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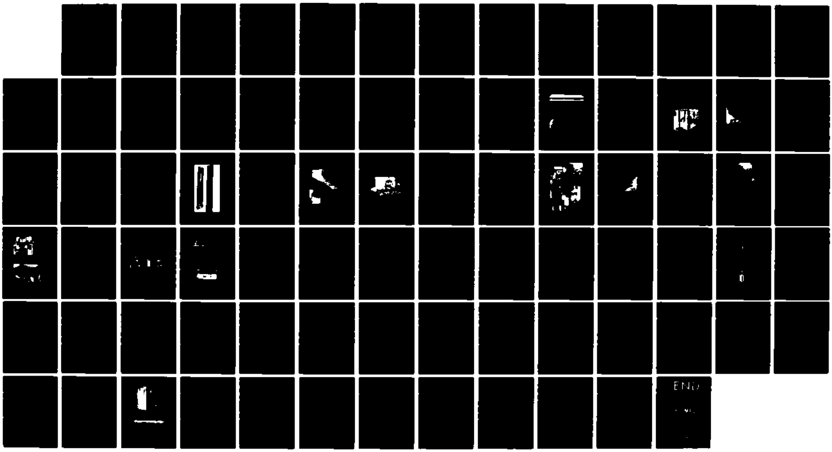

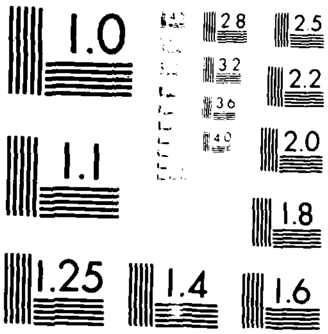

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

EXPERIMENTAL STUDY OF THE EFFECT OF MOIST ENVIRONMENTS ON EPOXY RESIN CHOCKS

by

George F. Wright

September 1984

Thesis Advisor: David Salinas

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Experimental Study of the Effect of Moist Environments on Epoxy Resin Chocks

by

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Submitted in partial fulfillment of the requirements for the degree of

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September 1984

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ABSTRACT

The widespread use of epoxy resin chocks to support alignment critical machinery on Naval ships has been hampered by the lack of a material specification, installation procedures, and maintenance information. Experiments were conducted to determine the effect of moist, shipboard environments on the compressive strength of the chocks, both during and after the curing process. Various techniques to accelerate exposure effects were investigated. Results indicated precautions are necessary for curing in low temperature/high humidity environments. Elevated temperature immersions and humidity chamber exposure proved to be useful methods to accelerate the studied effects.

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I. INTRODUCTION

Epoxy resin chocks have been periodically used for machinery support on U.S. Naval ships without a material specification, installation manual, or maintenance and inspection plan. This thesis will examine the effects of various exposures of potential engine room environments on an epoxy resin chocking compound. A comparison of data, obtained from several different exposure techniques to accelerate adverse environmental effects, will be made. Because actual exposure tests often must run for too long a time period to constructively enter into the design process, the validity of these acceleration techniques will be studied.

This research effort is an extension of an epoxy resin chocking compound test program conducted by the Naval Sea Systems Command, which welcomed additional research in this area at the Naval Postgraduate School. One of the topics studied by the Naval Sea Systems Command (NAVSEA) was to determine the degradation in compressive strength of the material after it was immersed in shipboard fuels and solvents. Emphasis was placed on the compressive strength of chocks because they are usually subjected to compressive loads in service. Additionally, the NAVSEA program was also interested in obtaining data from testing the material in as

close to actual service conditions as possible. This paper will examine the effect of fresh-water, salt-water, and oily engine room waste (bilge) water immersion over an eight week period on the ultimate compressive strength of chocks. It will then compare exposure to various moist environments at elevated temperatures to evaluate long term detrimental effects from relatively short term tests. In each case, a study will be made of the percent of moisture absorbed and the associated absorption rates. Finally, it will examine the effects of exposure to moist environments during the curing process on the strength of the material, and will compare the strengths of chocks cured in two different types of mould construction.

Observations about the material's behavior during all phases of experimentation will be made, which may be of use to NAVSEA's overall research program. Conclusions will be offered about the effect of a hot, moist environment on epoxy resin chocks, and an evaluation of the merit of accelerated tests versus long term exposure to actual service conditions will be made.

II. NATURE OF THE PROBLEM

A. BACKGROUND

The alignment of main propulsion engines, generators, pumps, and other shipboard equipment often is a long and tedious process when using the traditional method in which metallic shims are employed. The machinery is supported in place by hydraulic jacks or some other device, while steel shims are machined to fit exactly between the machinery foundation and the bedplate to which the equipment is being attached. The shims provide the necessary elevation for satisfactory alignment. This process could last for months and result in substantial labor costs in the case of large machinery.

Commercial shipbuilders and repair yards have been using pourable epoxy resin chocking compounds for over thirty-five years. The Navy has used these compounds on many shipboard jobs without a material specification or a technical installation manual. It has also been successfully used for main engine alignment on many large commercial vessels in the past. A detailed listing of marine applications of this material can be found in Ref. 1. Because of these problems, the Naval Sea Systems Command launched a three year test program to develop a material specification, certify shipboard material use, and develop a technical installation manual and quality control procedure.

Previous testing of this type of material has been conducted by the manufacturers, Lloyd's of London, Bell Aerospace, and Det Norske Veritas, the results of which are available in Ref. 2. Actual test results concerning the problem considered in this thesis are limited, and are reviewed later in this chapter.

A chock is a block or wedge, installed to prevent or limit motion. The pourable chock compound used for the experiments in this paper was Chockfast Orange, manufactured by Philadelphia Resins Corporation. It was chosen because of quick availability in the local area and the close proximity of a technical representative that provided the author assistance in learning how to properly use this material. For an actual installation, chocks are made by forming an enclosure between the bottom of the machinery and the bedplate to which it is being attached. This enclosure can be made with foam rubber strips or thin strips of metal (Figure 1).

The material comes in a two part kit consisting of a can of resin and a small plastic bottle of hardener. The physical composition of the materials was not available, although it apparently contains silica fibers and possibly some other abrasive filler material. The two parts are mixed together and then poured into the enclosure between the machinery and its foundation. After a specified curing period of 18 to 48 hours, which depends on the ambient air

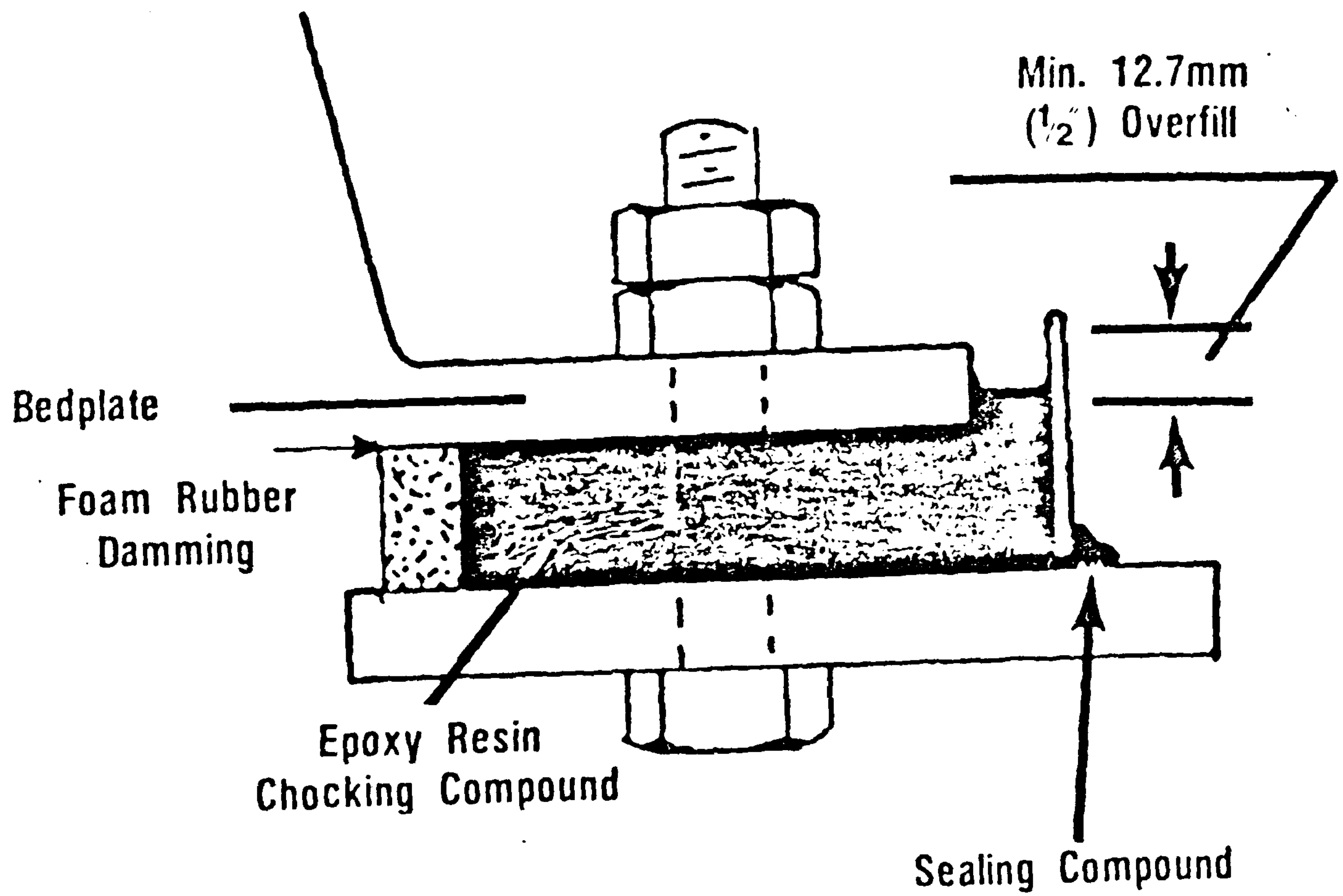

Figure 1. Chock [Ref. 3]

temperature, the material will have hardened. The piece of machinery will then be supported in its proper position by the hardened epoxy chocks. While the material is relatively expensive (one-hundred dollars for two-hundred cubic inches of material), the elimination of the long and precise machining process can result in substantial economical savings.

B. PREVIOUS WORK

Much research has been conducted to determine the performance of composite materials in environments that may be detrimental to their physical properties. Resin-matrix composite materials exhibit similar behavior to unfilled plastics when subjected to adverse environments in that the resin, not the reinforcement, will be weakened by moisture content. Experimental results indicate notable strength losses do not occur until moisture levels are about 0.6 percent [Ref. 4].

Research by Browning and Hartness [Ref. 5] examined the effects of moisture on the properties of high-performance structural resins and composites in 1974. Three of their conclusions are of interest:

(1) The effect of moisture absorption on epoxy material appears to be a reversible process. Test specimens that experienced a strength loss due to moisture absorption were dried and results indicated they recovered their strength properties. It would be desirable to know if chocks exhibit this quality.

(2) Specimens that were exposed to different moisture absorption processes were compared on the basis of water weight gain. They found that exposures to boiling water could be correlated with exposures to high humidity levels based on equivalent water weight gain.

(3) The mechanical properties were generally not affected by moisture contents up to a test temperature of 250 degrees F (121C).

E.C. Edge [Ref. 6], Principal Engineer with the advanced structural application department, British Aerospace, aircraft group, Warton Aerodrome investigated the effects of accelerated test methods on the properties of some composite materials. Two of his conclusions pertain to this thesis topic and are listed below:

(1) Immersion in boiling water appeared to give effects that were overly severe, in that there was noted a large proportion of damage that proved to be irreversible.

(2) Over acceleration produces the danger of excessive damage to the specimens even if the actual moisture level corresponds to what may be expected under actual service conditions.

Philadelphia Resins Corporation conducted a test according to American Society of Testing Materials (ASTM) D-57063 in which the full surface area of a Chockfast Orange casted sample was exposed to water for 365 days. The water absorbed was reported to be 1.2 percent, and is the only known

long term exposure test performed. Short term fresh-water and hydraulic oil tests were conducted by Lloyd's register of shipping, the results of which are shown in Table 1 [Ref. 7].

TABLE 1

Previous Test Results

	Fresh-Water	Hydraulic Oil
% Absorption after 24 hrs	.032-.035	.015-.122
% Absorption after 72 hrs	.055-.056	.021-.032

Finally, Philadelphia Resins Corporation conducted ASTM D570-63, which showed 0.67 percent water absorption after 119 days. The test results were annotated with the comment that the full sample area was exposed to water, where an actual chock would only have a small part of the total surface area exposed. Whether this fact has any bearing on the actual absorption rate will be investigated experimentally in this paper.

No previous work in this field had been conducted at the Naval Postgraduate School; consequently, many decisions were influenced by the need to develop a reasonable way to collect data in a very short period of time. Recommendations will be offered for refinement of particular test methods to facilitate future research.

III. EXPERIMENTAL APPARATUS AND PROCEDURE

A. MOULD CONSTRUCTION

1. Geometry

The first problem faced by the author was what size to make the chocks. Almost all previous work on this material and similar epoxy resins utilized standard ASTM specimens, which are generally small blocks or disks. For example, ASTM D695 for determining the modulus of elasticity uses a sample that is 0.50-by-0.50-by-1.0 in thick. Actual chocks in service are on the order of 6-by-6-by-1.5 in thick and the Naval Sea Systems preliminary testing indicated the modulus of elasticity is dependent upon the dimensions of the chock. While this question was not within the scope of this paper, an effort was made to design the test specimens to fit the dimensions of an actual chock that may be found in service to make the results more indicative of actual expected service. This motive has resulted in some deviations from ASTM testing standards throughout the experimental procedure. While these deviations make data comparison to other research in the literature difficult, the data will be much more useful to the Naval Sea Systems Command, and may be used to corroborate their results.

The maximum test specimen load bearing area was determined by the availability of test machines at the Naval

Postgraduate School. Although consideration was given to using larger test machines at other universities, the need to keep the specimens in humid environments until just before testing ruled out this option for logistical reasons. Preliminary calculations indicated a 100,000 pound compression testing machine would not be adequate for any size specimen that may be found in service, therefore, a 200,000 pound Tineus Olsen testing machine was selected. With an estimate of 20,000 PSI for the ultimate compressive strength of the material, a 3-by-3 in chock would have approached the maximum limitation of the machine. As a result, a 2-by-2-by-1.25 in specimen was chosen. This was one of the sizes to be tested by the Naval Sea Systems Command project and the selection of the 1.25 in dimension for thickness was made because it is a common thickness used in service.

The material properties of chocks may be a function of the casting process and the volume of the material poured. This is a topic under study by the Naval Sea Systems Command, the results of which were not available to the author. One 15 pound unit of Chockfast Orange produces approximately 200 cubic inches of epoxy resin material when poured into a mould. The moulds were designed to use as much of the material from one unit as possible because, once mixed, the material has a useful time of about 20 to 30 minutes. It was decided to split the pour into two moulds because a very large volume pour produces an exothermic reaction which may

produce high temperatures inside the mould. The manufacturer recommended an allowance of ten percent extra material for shrinkage and a portion of each pour was used for another mould that would be more representative of the way chocks are made in service.

2. Material

Experience in mould making at the Naval Postgraduate School was limited primarily to silicon type moulds. Silicon provides rigidity when used in sufficient thickness, while it also produces great detail, and it was felt that it would provide satisfactory surfaces required for testing purposes. Plaster was briefly considered but discarded because of the lack of detail producing qualities and the possibility that it might crack during the curing process of the chocks. Silastic RTV (J), manufactured by Dow Corning, was chosen for the mould because both the material and personnel with experience in its use were locally available.

3. Primary Mould Construction

An aluminum bar (Figure 2) that was machined to the exact dimensions desired for the test samples served as the object that the mould material would be formed around. A box made from plexiglass was fabricated around the aluminum bar and sealed together with melted wax. The bottom half of the mould was poured first and the RTV was allowed to cure. Then the top half of the mould was made by simply building a new box out of plexiglass and pouring the RTV right over

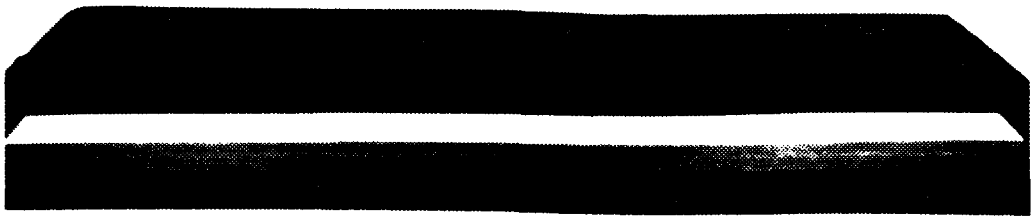

Figure 2. Aluminum Bar for Primary Mould

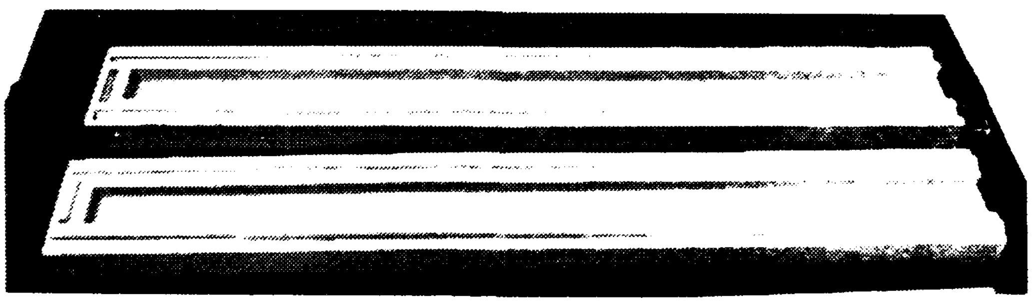

Figure 3. Primary Mould

the cured bottom portion of the mould. RTV will not adhere to itself, but a light coating of petroleum jelly was applied to the surface of the bottom half of the mould just to ease in releasing the two halfs after the top half had finally cured (Figure 3). A modal maker fabricated the plexiglass box and poured the first mould, while the author formed the plexigalss box and made the second mould. RTV, as with Chockfast Orange, comes in a two part kit with the RTV material and a can of hardener. The two were mixed together and then placed in an evacuation chamber (Figure 4), which removed the air from the material. The first batch of RTV poured was not evacuated due to an equipment failure and bubbles were detected on the surface of the mould, however, the quality of the internal portions of the mould was not affected.

A different type of mould was required to cure the material at various temperatures and high levels of relative humidity. The silicon moulds were too large for the humidity chamber, so a small mould was designed to utilize the remainder of each pour. An additional feature of this mould was that it resembled an actual type installation much more so than the silicon moulds (Figure 5).

B. TEST SAMPLE FABRICATION

1. Material

The Chockfast material comes in a 15 pound, 220 cu in unit which consists of a can of resin and a 17 oz plastic

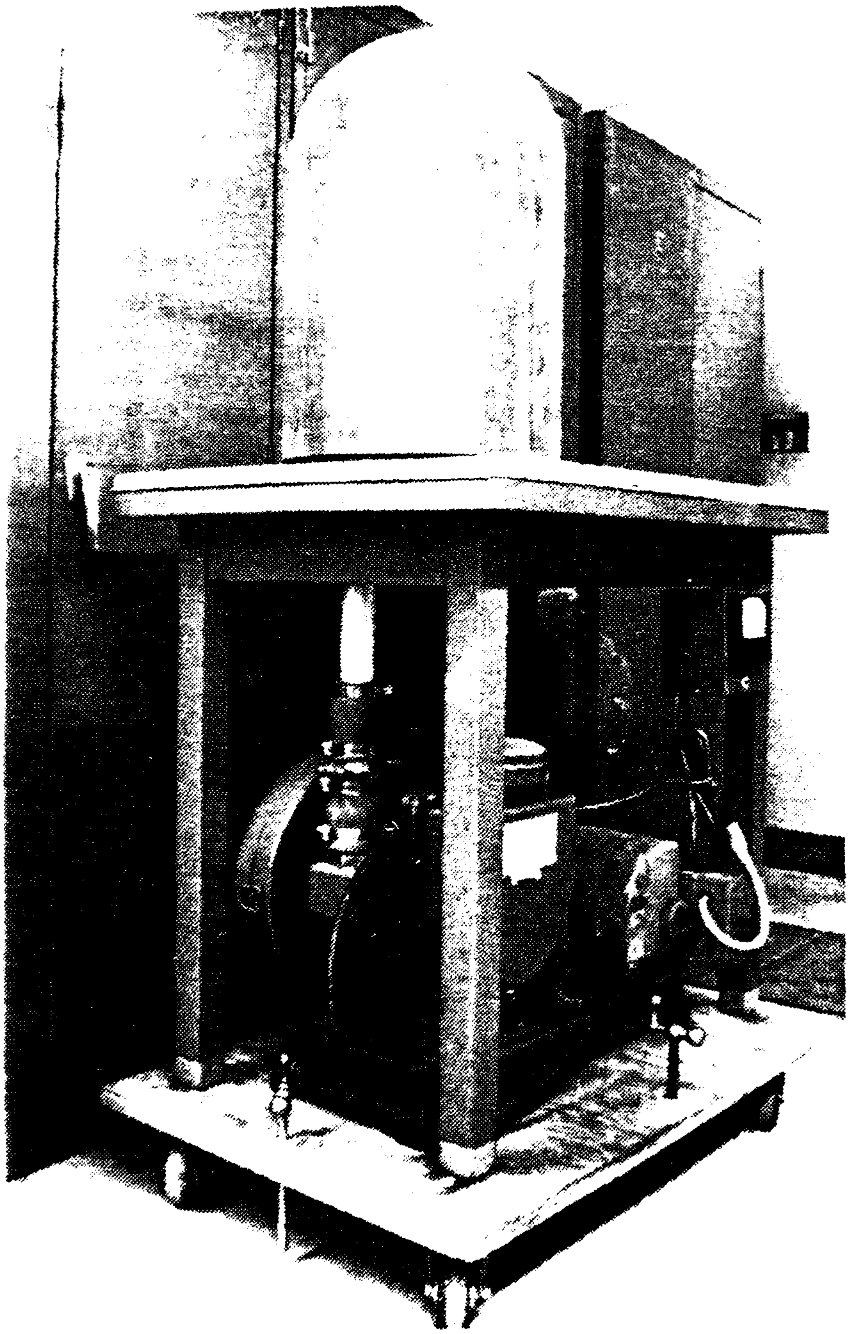

Figure 4. Simulation Chamber

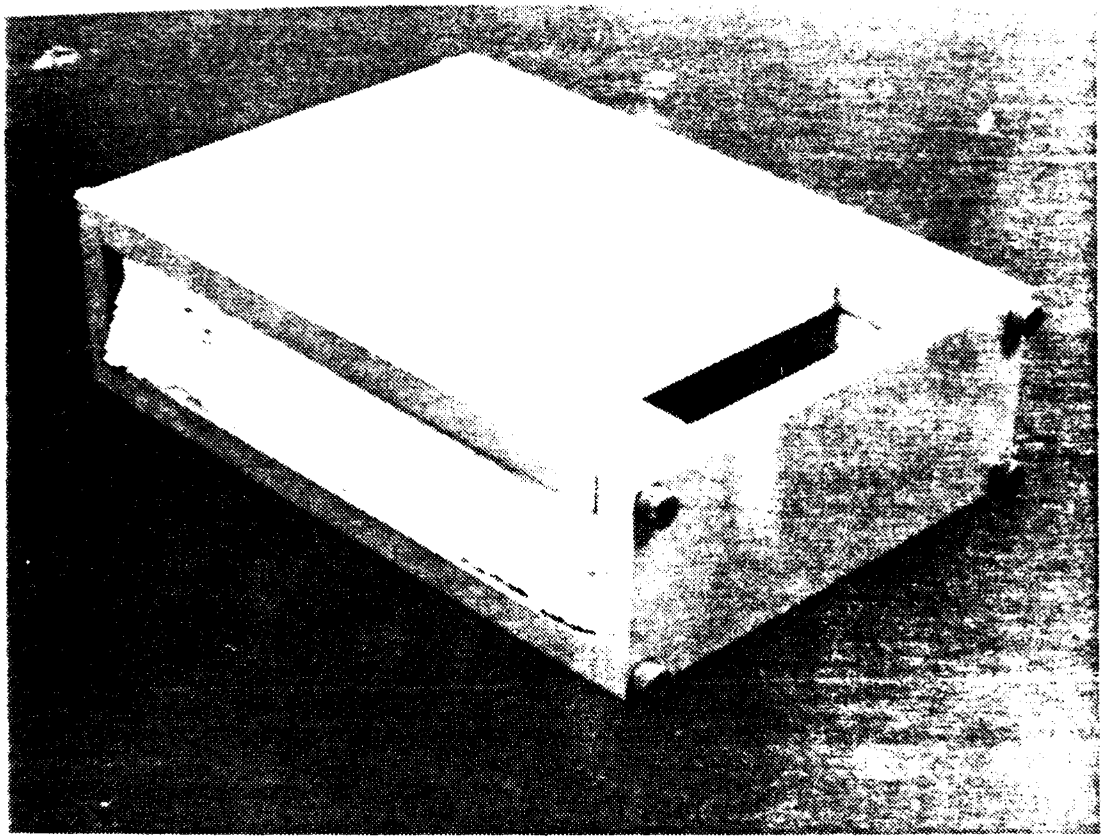

Figure 1. Secondary Model

bottle of hardener (Figure 6). The material was obtained directly from the Philadelphia Resins Corporation west coast sales office and all material used in this experiment was from the same lot.

Because of the large size of the primary mould and the fact that silicon is generally considered to be a good insulator, there was some initial concern that the temperature inside the mould would become very high during the curing process, and its impact on the ultimate compressive strength was not known. The manufacturer recommended the use of a full reduction of hardener when using silicon moulds, which amounted to using the quantity above the pour line as shown in Figure 7. This procedure was adhered to throughout the course of the experiment, even in the case of the small secondary mould. It was not certain whether this reduction of hardener would affect the strength of the samples extracted from the small secondary mould because it was fabricated from aluminum which would allow heat transfer to take place exactly as it would in an actual application. As a result, the ultimate strengths from the two different moulding processes will also be examined.

2. Mix, Pour, and Cure Process

Philadelphia Resins Corporation Technical Bulletin No. 652A [Ref. 8] was followed with a few minor exceptions noted later in this paper. Protective gloves and safety glasses were worn during the mixing and pouring processes.

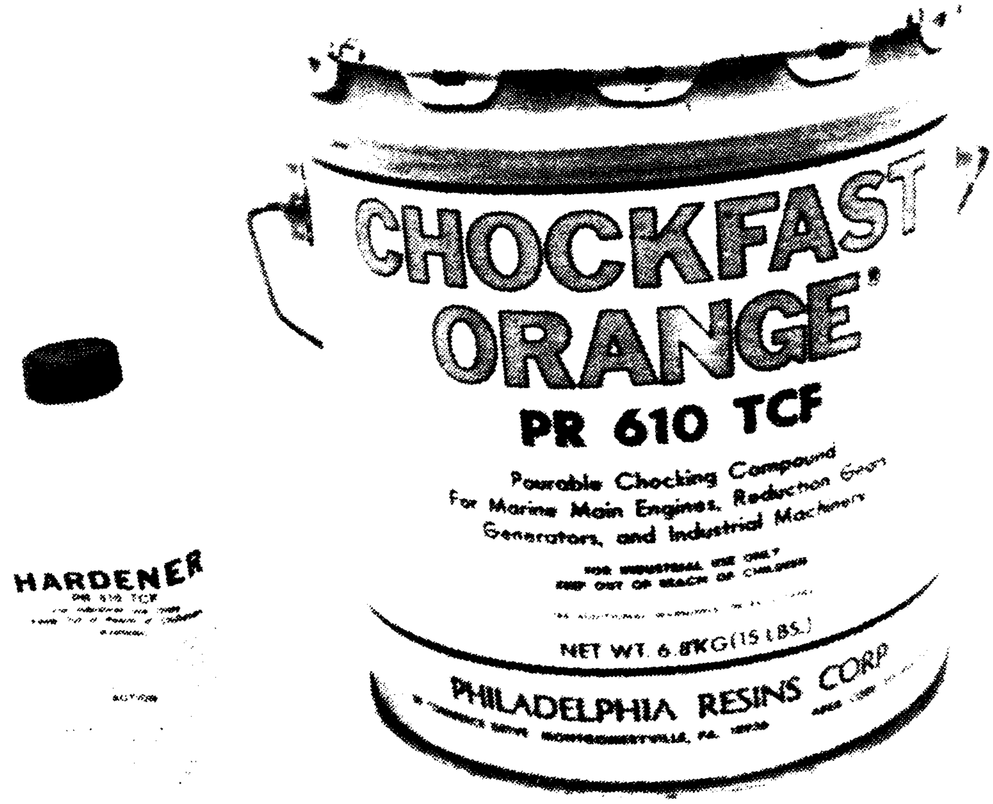

Figure 6. Chockfast Orange and Hardener

Figure 7. Reduction of Hardener

The hardener (full reduction employed), was poured into the can of resin and power mixed with the proper mixing blade at approximately 200 rpm for three minutes. The thoroughly mixed material was then allowed to stand for 10 minutes to let any entrapped air escape to the surface. This was a deviation from the manufacturer's procedure which simply says to pour the material shortly after mixing. The moulds were cleaned and coated with a thin coating of petroleum jelly to allow easy separation after the curing process was completed. Plywood boxes, one for each half of the mould, were fabricated and clamped around the mould to hold it together (Figure 8). The material was then poured into the moulds while they were held at a slight incline (approximately 5 degrees from the vertical). Bubbles were noted rising to the surface after the pour was made, which indicated some air was able to escape, although it was not known how much air remained entrapped inside of the mould.

The mould was allowed to cure for 48 hours at an ambient temperature of between 72 and 78 degrees F. After removal of the long bar of cured Chockfast material, significant deformation was noted where the clamps had been applied to hold the mould together. Another pour was made with the clamps only lightly tightened, which resulted in serious leakage of the material out of the sides and the bottom of the moulds. Plywood sheets approximately one-half inch thick were substituted for the wooden box previously used to hold

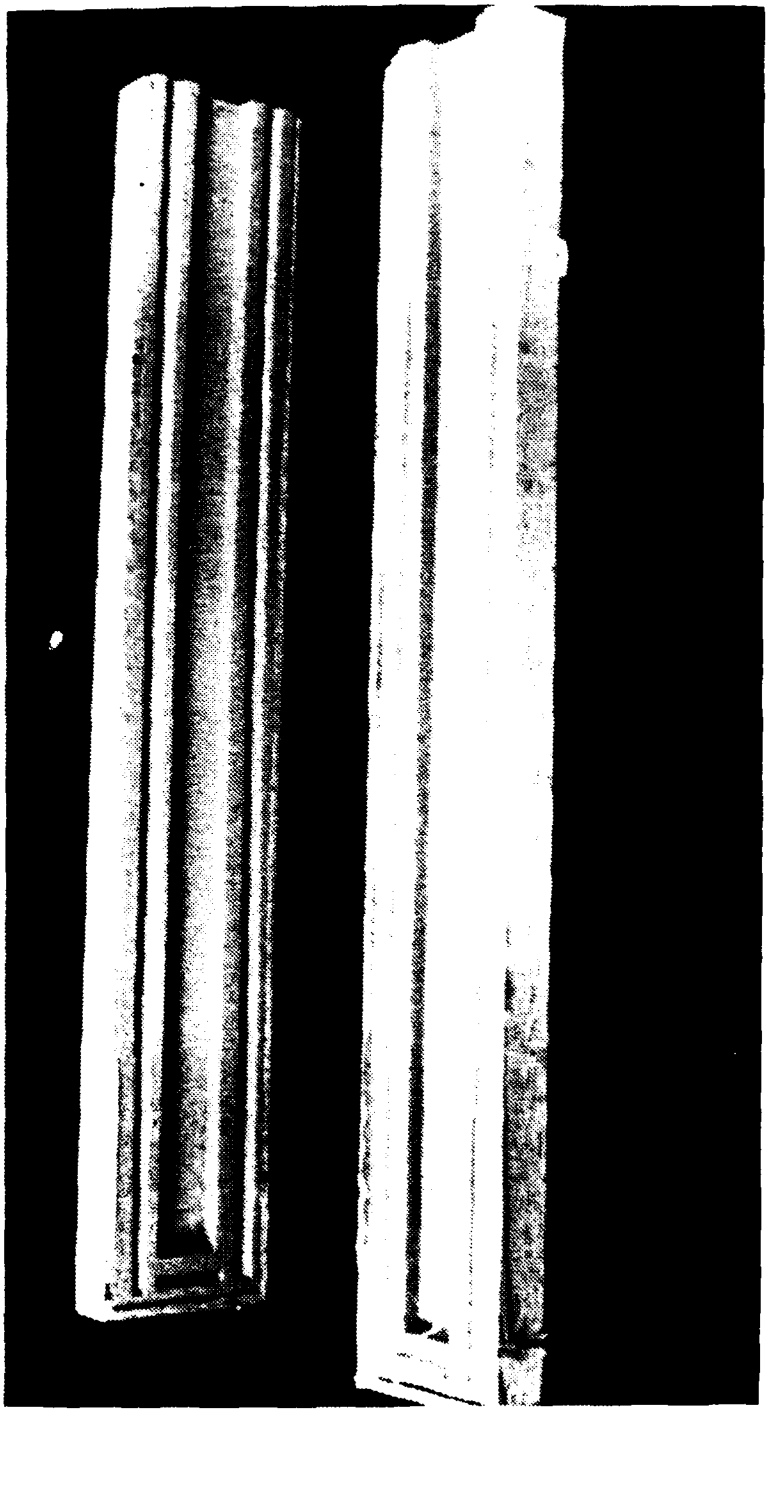

Figure 8. Mould Contained in Plywood Boxes

the moulds together. Bolts were used along each side to apply a more uniform load along the length of the mould (Figure 9). This proved relatively successful, although these measures would not have been necessary if a more rigid mould material had been used.

3. Cutting the Chocks

The Chockfast material apparently has some percentage of silica fibers and other abrasive filler material which is very destructive to normal industrial cutting tools. Additionally, the insulating qualities of the material do not allow the heat generated during the cutting process to dissipate. A wood cutting band saw blade was used to cut approximately 20 samples after which all of the teeth on the blade had melted. A steel cutting saw with oil cooling was then tried with the same results. A diamond saw with water cooling was eventually chosen and performed satisfactorily throughout the course of this experiment (Figure 10).

C. HUMIDITY CHAMBER

One portion of this thesis required the aging of chocks in an environment that could accelerate any destructive effects that moisture absorption may have on the material. As discussed in Chapter II, the literature contains references to the Warton "fast chamber" which was used to age composite materials at 90 degrees C and 95-100% relative humidity (RH), as well as boiling water immersion tests. The intent of this part of the experiment was to compare the

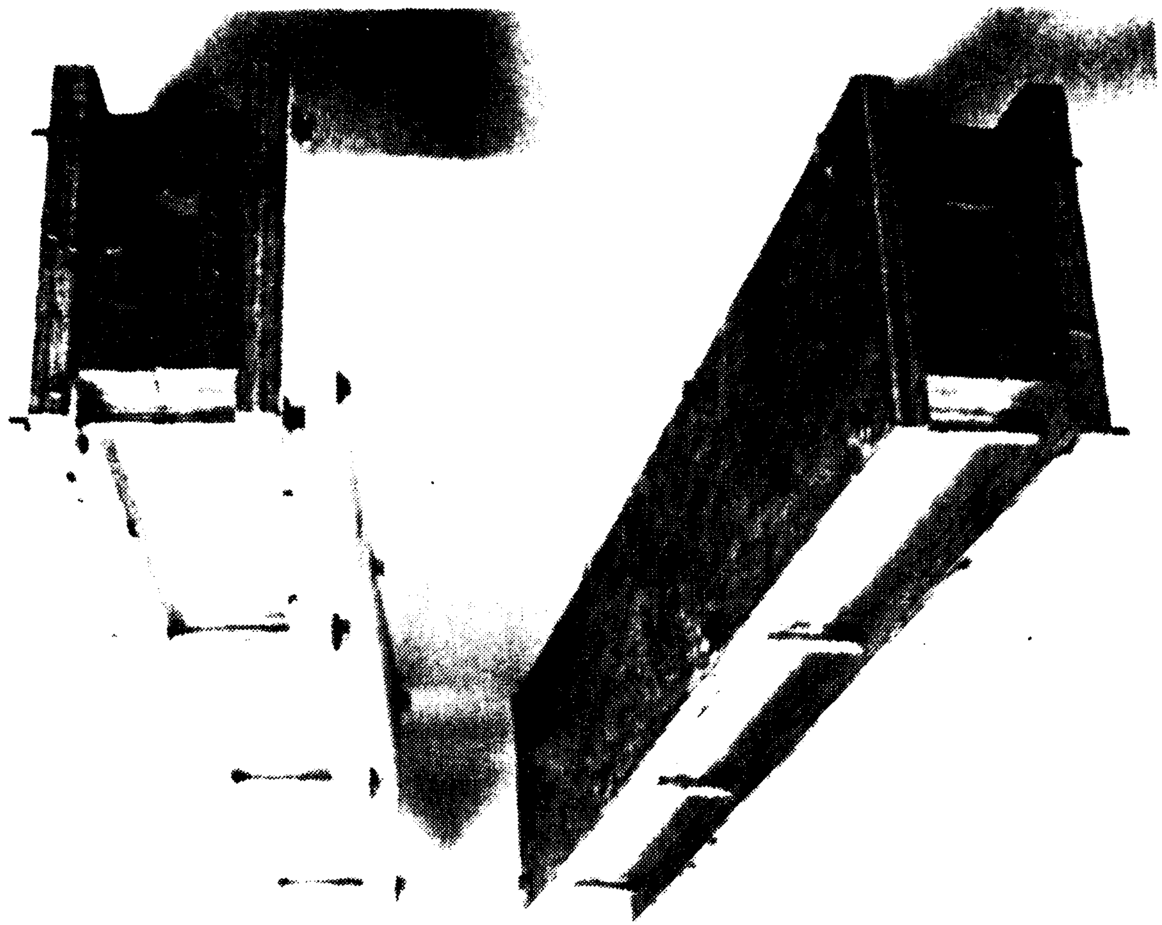

Figure 9. Mould Held Together by 1/2 in Thick Plywood Sheets and Bolts

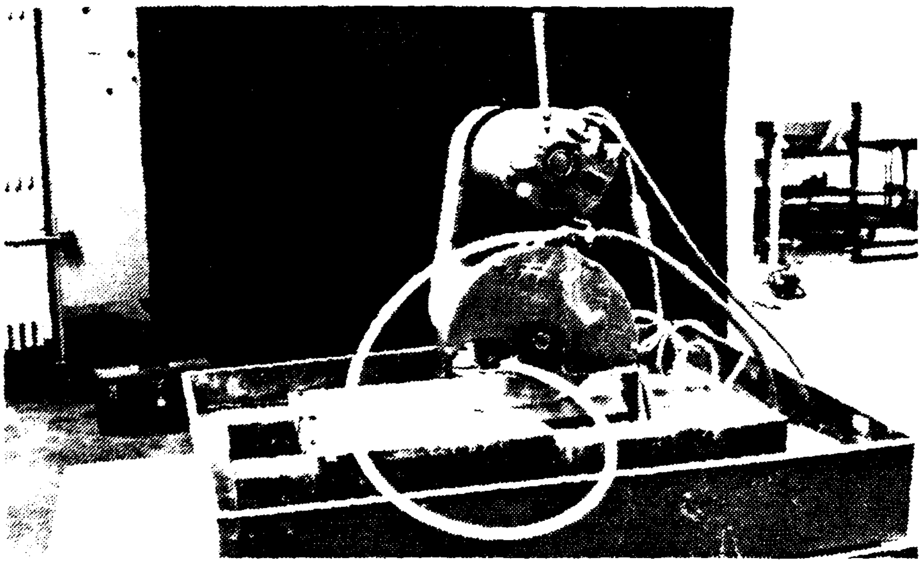

Figure 10. Diamond Saw Used for Cutting Chocks

results of samples aged in water at an elevated temperature and samples aged in a controlled humidity exposure that more closely represents what might occur service. It is considered unlikely that engine and other equipment foundations will actually be submerged in liquid for a long time, but their close proximity to hot, humid environments is very possible. A Blue M humidity chamber was located in storage at the Naval Postgraduate School with no past records of service, maintenance, or operation. An operation manual was obtained from the manufacturer and the cabinet was moved to a suitable location and placed into operation. The greatest problem encountered was the fact that the humidity cabinet required a demineralized source of water for satisfactory operation. Proper temperature and humidity control was heavily dependent upon clean heat transfer surfaces, and fouling due to mineral deposits from ordinary tap water was intolerable. Distilled water was available but had to be transported to the humidity cabinet from another building, and the consumption rate of water was reported to be between 5 and 10 gallons for 24 hours of continuous operation. Since one of the experiments was planned to run for six weeks an alternative to portable transportation of a demineralized water supply had to be found.

Two tanks formed the basis of a water purification system. One tank was installed on top of the cabinet and gravity fed through a water filter to the supply side of the humidity

chamber. The other tank was installed directly alongside the cabinet to serve as a condenser (Figure 11). A stainless steel 3 in diameter pipe was installed from the vent of the chamber to the lower tank. This was necessary because at continuous 80 degree C/95-100% RH operation the chamber consumed nearly eight gallons of water per day given off as steam. This lower tank acted as a condenser for the steam that would have otherwise been vented to the atmosphere. A pump was installed to propel the condensate back up to the upper tank when required. This water purification and conservation system reduced water consumption to negligible quantities, which were primarily lost as steam when the cabinet door was opened for the removal of samples for testing (Figure 12). The installation of an automatic float switch in the lower tank that would activate the pump would be a slight improvement to the system, but was not considered necessary as the system operated about one week before the lower tank had to be pumped.

D. METHOD OF DETERMINING ABSORPTION

After the initial weights of the chocks were recorded, their weights were monitored after various exposures to liquids and moist environments. The assumption was then made that the weight gain was equal to the weight of the liquid absorbed by the sample. This is similar to the most common process to determine the amount of water in a solid material: weigh the sample, dry it in an oven, and weigh

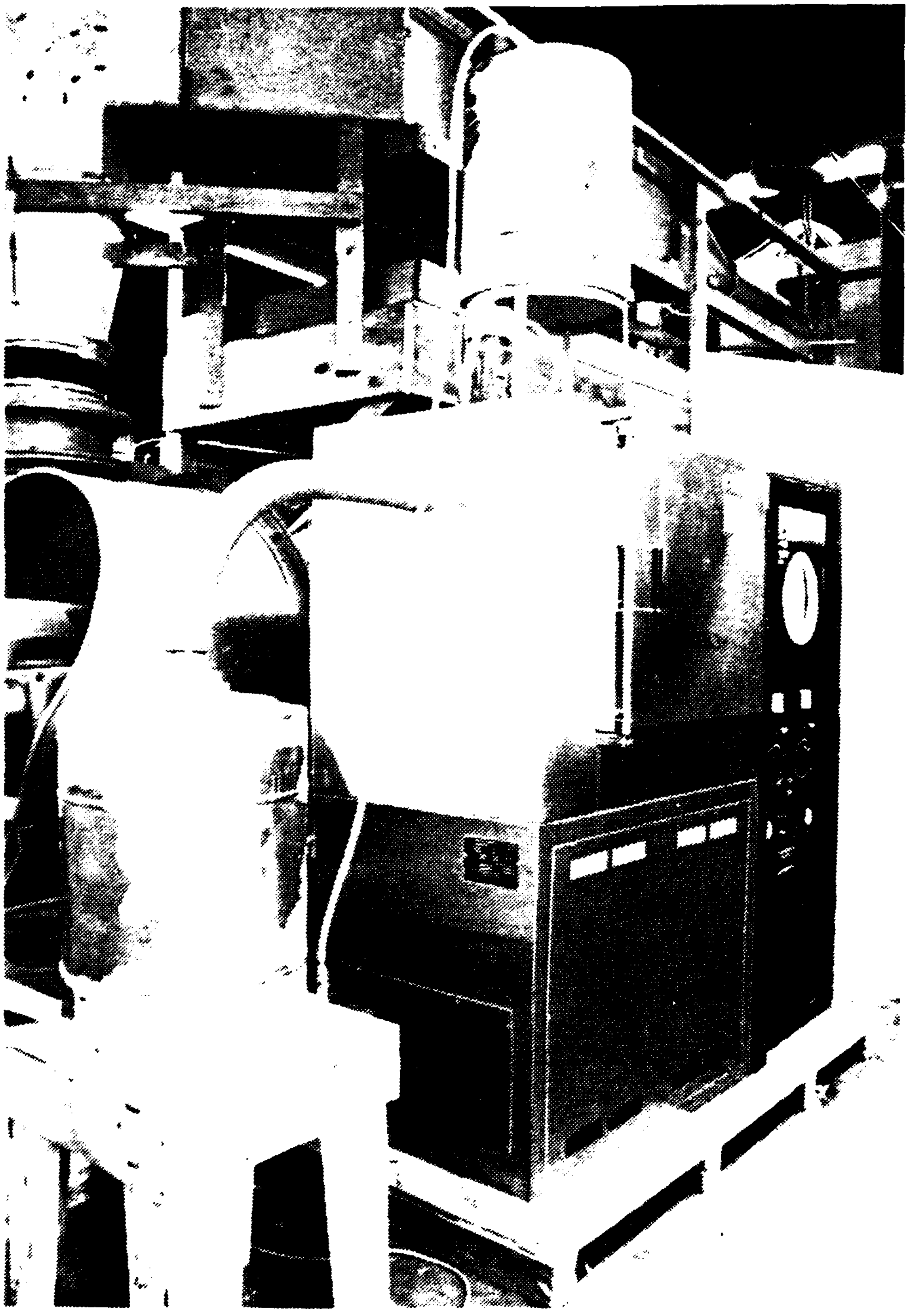

Figure 11. Humidity Chamber

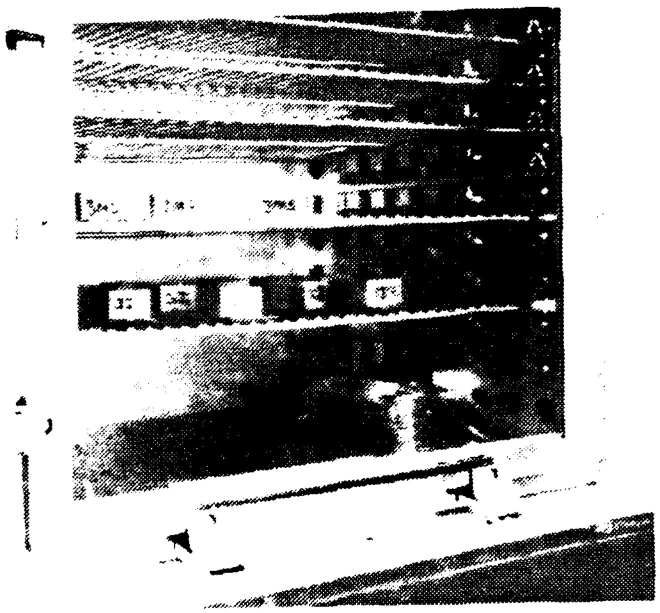

Figure 12. Chocks Exposed to 95-100% RH Inside Humidity Chamber

it again assuming that the weight loss is that of the water that was in the sample [Ref. 9]. Limitations to this method exist, however, because other processes like decomposition of one of the constituents of the material could take place. This could result in the removal of the water soluble constituents to the immersion fluid thereby making iterpretation of the test results difficult. The method chosen, despite the above listed drawbacks, is well founded and is prescribed by ASTM D-543-67 Standard Method of Test for Resistance of Plastics to Chemical Reagents.

A Mettler Instrument Corporation Precision Balance capable of measuring samples up to 160 grams was used for all weight measurements (Figure 13). The balance was graduated to a tenth of a milligram and its readability was considered to be plus or minus 0.0001 grams on a vernier scale. Although the weighing process is subject to error as in any other experimental process, errors are typically on the order of fractions of a milligram [Ref. 10]. Other sources of error could be that the chocks were not wiped completely free of moisture on the surfaces before being weighed, some drying took place prior to the samples being weighed, or that weighing some of the samples while still hot created convection currents within the balance case. After having taken all of these possible sources of error into account, a conservative error margin was considered to be plus or minus 0.005 grams, which was used in the uncertainty analysis for precision measurements.

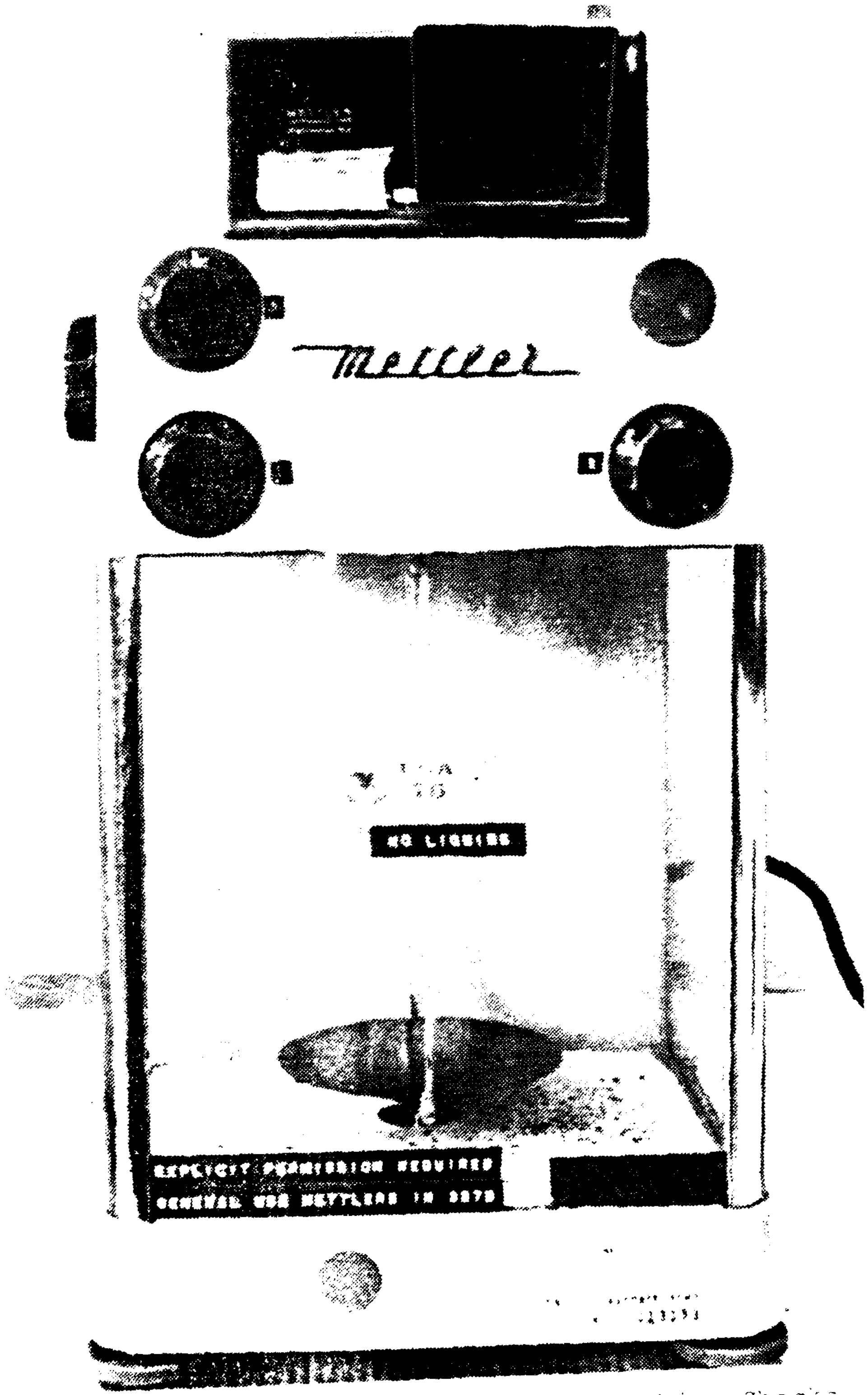

Figure 13. Precision Balance for Weighing Checks

E. COMPRESSION TEST PROCEDURES

In general, ASTM D695-69, Standard Method of Test for Compressive Properties of Rigid Plastics was used as a guideline for the compression testing performed during this experiment. Because of the use of a non-standard size specimen, a machine with a load capacity of greater than 100,000 pounds force was required to achieve as realistic conditions as possible. There were no machines available with load-deformation automatic data recording capabilities for loads in excess of 100,000 pounds. Although a system could have been designed and implemented, it would have contributed to a considerable delay in the data gathering process. Since the time available for this experiment was brief, further delay to install an automatic data recording system could not be tolerated.

A 200,000 pound capacity Tineus-Olsen hydraulic universal testing machine was chosen for all compression testing (Figure 14). The chock was placed between the load plates and a dial indicator was used to measure the deformation in the chock. Plots were initially made of six test samples and stress-strain data plotted in a linear fashion until the yield point was reached. The dial indicator had to be mounted on a block and shims were designed and machined to provide the proper clearances. A pad for the test specimen was also made out of Stainless Steel 304 to provide the proper clearances for the dial indicator (Figure 15). A

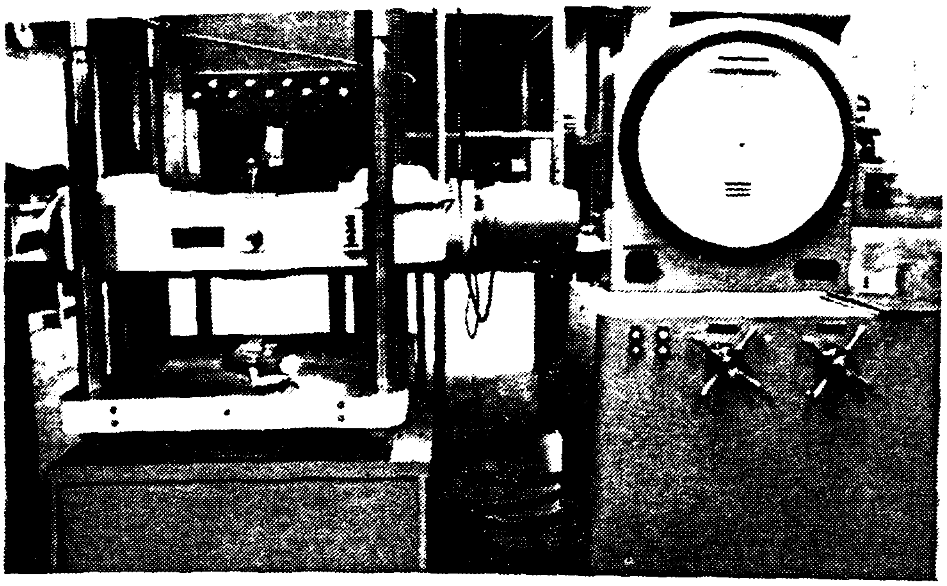

Figure 14. Tineus-Olsen Super "L" Hydraulic Universal Testing Machine

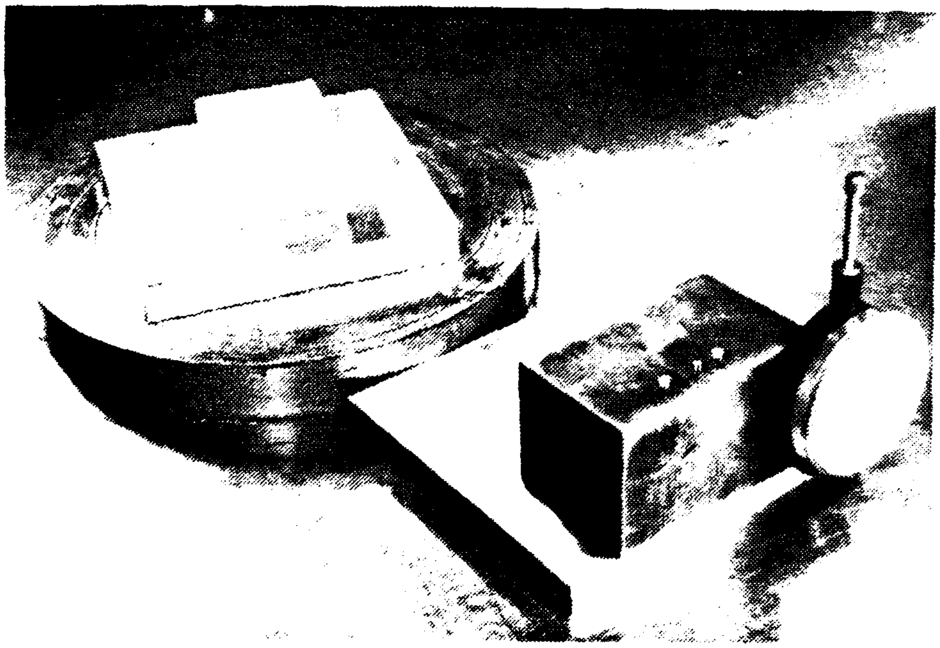

Figure 15. Chock in Test Machine With Dial Indicator

uniform loading rate was maintained throughout the testing and was determined to be within the ASTM recommendation.

F. IMMERSION BATHS

Plastic tubs with metal racks were used for the room temperature immersion test. The samples were placed on the racks so as to expose as much of the surface area as possible to the immersion fluid. Two constant temperature immersion baths were also acquired for the testing; one primary and one serving as a spare (Figure 16). The primary bath developed a leak after one week and the standby functioned satisfactorily throughout the remainder of the experiment. The baths were maintained at 80 degrees C plus or minus 2 degrees C.

G. EXPERIMENTAL PROCEDURES

1. Room Temperature Immersion Test

The purpose of this test was to determine the rate of absorption for chocks immersed in various fluids and what effect, if any, the immersion had on the ultimate compressive strength of the material. This data was then compared to results from accelerated processes to observe if accelerated tests produce oversevere or inaccurate results.

A control was established randomly from a group of 32 chocks made from one pour of Chockfast Orange, and a sufficient number of chocks were placed on metal racks in the three immersion tubs (Figure 17). The three immersion fluids used were fresh-water, salt-water (3.2% by weight),

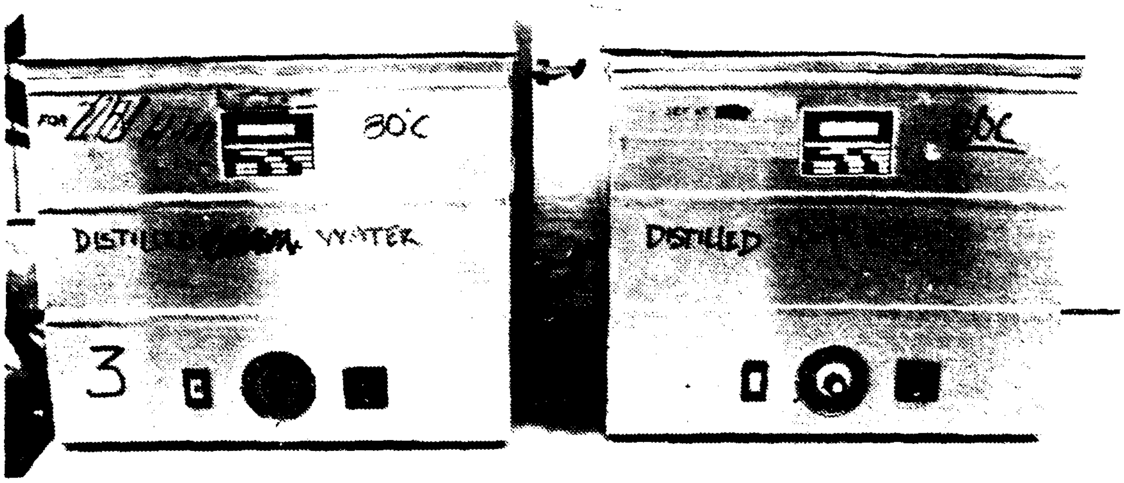

Figure 16. Immersion Baths

Figure 17. Salt-Water Immersion Bath

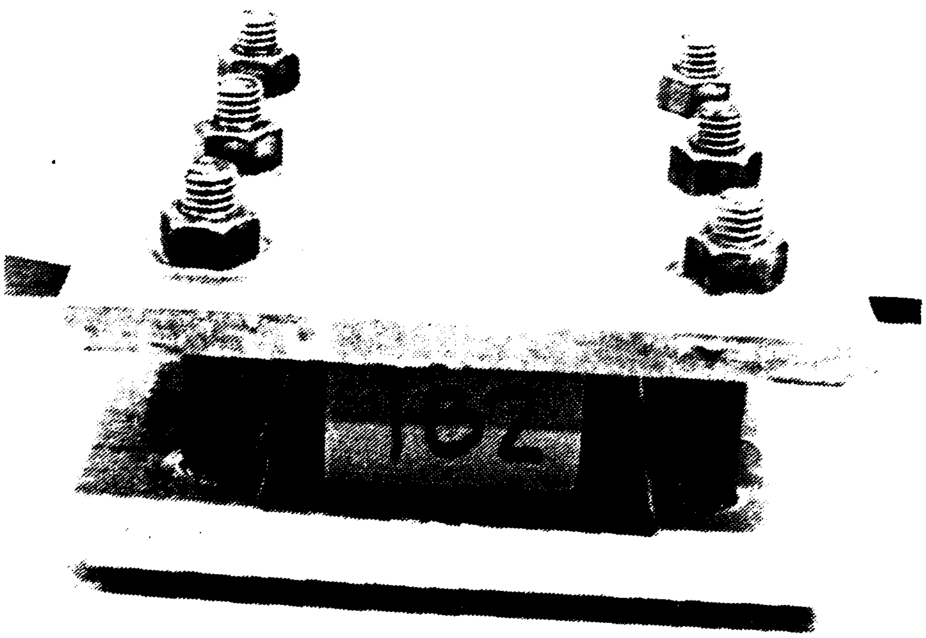

Figure 18. Chock with Only Partial Surface Area Exposed

and oily engine room bilge water. The intent of the use of bilge water exposure was to observe if a mixture of diesel oil, lube oil, salt-water, solvents, dirt, etc. could possibly have a detrimental effect on the material. Tests have been conducted with exposure to clean fluids such as hydraulic oil and fresh-water, however, chocks are much more likely to come in contact with dirty, used materials. The oily bilge water was obtained from the USCGC PT. BARROW and is considered to be typical of that which might be found in any diesel plant.

Three control samples for each fluid were monitored throughout an eight week period. Weight gains, color, and any changes in dimensions were recorded. Two chocks for each fluid were placed in between two stainless steel plates that were bolted together (Figure 18). Gasket material was used between the chocks and the plates to maintain an adequate seal across the surface of the chocks. This is more typical of the way an actual chock would be exposed, with only the edges of the material being open to the environment, as the top and the bottom would be covered by the bedplate and foundation. The purpose of this particular test was to show whether actual immersion of an installed chock would lead to a significantly lower absorption rate; hence, less effect than the full surface area exposure would indicate.

Finally, three samples from each fluid were removed and tested at four week intervals to see if there was a

significant reduction in ultimate compressive strength due to the exposure of the materials to their respective environments.

2. Exposure During Curing Process Test

The purpose of this test was to determine if a high humidity in the vicinity of the curing material had any effect on its ultimate compressive strength. There were no warnings from the manufacturer regarding humidity or moisture precautions so this test was developed to determine if a certain combination of temperature and humidity was detrimental to the curing process. The manufacturer's instructions for using the pourable epoxy resin compound does state that the plate temperature around the chocks be maintained at a minimum of 60 degrees F (16 degrees C) with hot air blowers, if necessary [Ref. 11]. The temperatures selected for curing the material were 15C, 22C (control), 25C, and 40C. The humidity was maintained between 95 to 100% relative humidity throughout the entire curing process. The cold temperature was selected particularly because some shipyards in the Northeast have not used the material because of the problem maintaining the minimum acceptable temperature. Since many days in the Northeast are also accompanied with snow, ice, and rain, the combination of 15C, 95-100% RH conditioning was deemed appropriate. At the other extreme, 40C and 95-100% RH was intended to represent curing the material on a typical day in a hot, humid environment.

The Chockfast material was poured into the small, aluminum mould and the mould was placed in the humidity cabinet at the appropriate conditions for 48 hours at an incline of approximately 5 degrees from the horizontal, after which specimens were cut and tested for compressive strength. The block of epoxy material extracted from the mould assembly cured at 15 degrees C could not be immediately cut with the diamond saw. The material became gummy and loaded down the blade, reducing the RPM until the blade stopped rotating. The chock was then allowed to cure at approximately 70 degrees F an additional 48 hours, after which it was easily cut with the diamond saw.

3. Humidity Chamber Exposure Test (80 Deg C, 95-100% RH)

This test commenced after completion of the previously described experiment because it required the humidity chamber to be maintained constantly at the same test temperature for a period of 8 weeks. The purpose of this test was straightforward: to determine whether chocks exposed to the highest temperature they are expected to see in service (80 degrees C) at a maximum relative humidity will experience any detrimental effects. Additionally, the acceleration of moisture absorption by this method was observed and compared to exposure by other methods. Test samples were placed in the humidity chamber and a control of three samples was monitored regularly for weight gain and dimensional changes as in the other tests. The samples were removed from the chamber at specified times and placed in a container of

fresh-water for one hour prior to compression testing to allow them to cool to approximately 25 degrees C. The samples were compression tested every week, with their strengths recorded to determine if a loss occurred.

4. Elevated Temperature Immersion Test

The purpose of this test was to increase any destructive effects moisture may have on chocks by accelerating the process with increased temperature. An additional development that was examined was the comparison of the moisture absorption rate observed in this test to that observed in the other tests. The samples were placed in a constant (plus or minus 2 degrees C) temperature immersion bath and maintained at 80C for 6 weeks. A three sample control was again used to monitor weight gain. Samples were removed for testing after 24 hours, 72 hours, one week, two weeks, three weeks, and 6 weeks.

5. Edge Absorption Rate Test

This test was developed because the moisture absorbed in the room temperature immersion test was not proportional to the surface area exposed, and the possibility existed that the chocks were absorbing more water through the edges that were cut with the diamond saw. It seemed reasonable that the chocks with only the edges exposed should have absorbed less moisture than the samples with the entire surface area exposed. Six chocks were used in this experiment. Three chocks had only the as-moulded edges exposed;

the diamond saw cut edges were sealed with RTV. The other three samples had only the two diamond saw cut edges exposed, while the cured edges were coated with a silicon sealer. It should not be concluded that because the chocks were machined by cutting that these test results are overly conservative. Chock edges are generally not machined after installation, but bolt holes are often drilled through the chocks after curing. The chocks were monitored for weight gain throughout a three week period to determine which samples had a greater increase.

IV. DATA ANALYSIS

A. ABSORPTION RATES

Weight gains for all experiments were calculated by weighing the chocks before exposure to a particular environment, and then weighing them again after exposure at regular intervals. Most of the experiments employed a sample size of three, with a few exceptions where only two samples were used. The percent weight gain was calculated using the following formula:

(final wt-initial wt)/initial wt x 100 = % weight gain

Average percent gains in weight were then reported in accordance with ASTM D543-67 and plots of the weight gain versus time were made. Additional plots were generated to compare full surface area exposures with partial area exposure, and accelerated exposure with ambient exposure.

B. ULTIMATE COMPRESSIVE STRENGTHS

The ultimate compressive strength for the chocks was obtained by the procedures set forth in Chapter III.E, Compression Test Procedures. The maximum load achieved by the chock and its load bearing dimensions were used in the following calculation:

Max Load/Area = Ult. Compressive Strength

In all cases the three chocks with the same exposure conditions were tested and data was examined for consistency. A common sense approach was employed to eliminate a chock sample if results were totally inconsistent with the other two chocks.

As in the moisture absorption portion of the experiment, the average ultimate compressive strengths were plotted versus time of exposure for the various tests.

C. HUMIDITY CHAMBER EXPOSURE DATA

Power to the humidity chamber was disrupted intermittently during a 28 hour period between 40 and 50 days of exposure time. The conditions inside the chamber dropped to 50 degrees F and 92% RH. A portable generator was used to maintain test conditions during most of this period. Since the total exposure process took place over a six week period, a small interruption of this magnitude was not considered significant. Results indicated the power interruption had no apparent effect on the moisture absorption rate for the chocks.

D. ERROR ANALYSIS

An error analysis was performed for the percent weight gain, stress, and strain calculations. The results of this analysis are listed below with accompanying calculations in Appendix B [Ref. 12].

stress	:	100 psi
strain	:	0.001 in/in
% wt gain	:	0.003 %

V. RESULTS

A. ROOM TEMPERATURE IMMERSION TEST

The material appeared generally resistant to the various fluids tested. Dimensional changes were insignificant; swelling due to the absorption of moisture or oil did not occur. Immersion in fresh and salt-water had no effect on the color of the material; however, the samples that were exposed to oil became darker with time. Figure 19 shows chocks 1K1,2, and 3 which were exposed to 4 weeks of fresh-water, salt-water, and oily bilge water respectively.

Figure 20 shows the percent weight gain versus time for the samples immersed in the three different fluids. After an initial rapid absorption period during the first 10 days, the chocks experienced a nearly linear weight gain, except in the case of oil exposure which appeared to taper off more than the other two fluids at about the 35 day mark. The absorption rate for all three fluids was approximately 0.0012-0.0015 percent weight gain per day. The rate for fresh-water absorption was substantially lower than those reported in previous testing discussed in Chapter II; however, the oil absorbed after 72 hours was about the same as observed by the Lloyd's test for hydraulic oil immersion.

The surface area to volume ratio was calculated for the ASTM test size samples used in early tests by Philadelphia

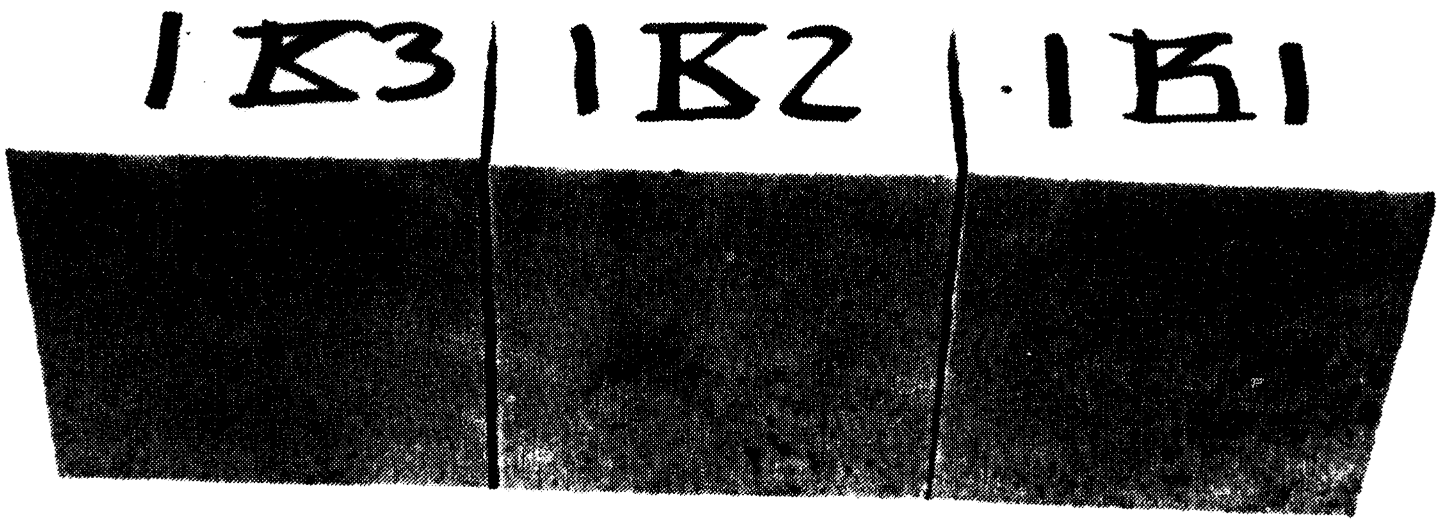

Figure 19. Chocks Exposed for 4 Weeks to Bilge Water, Salt-Water, and Fresh-Water (from left to right)

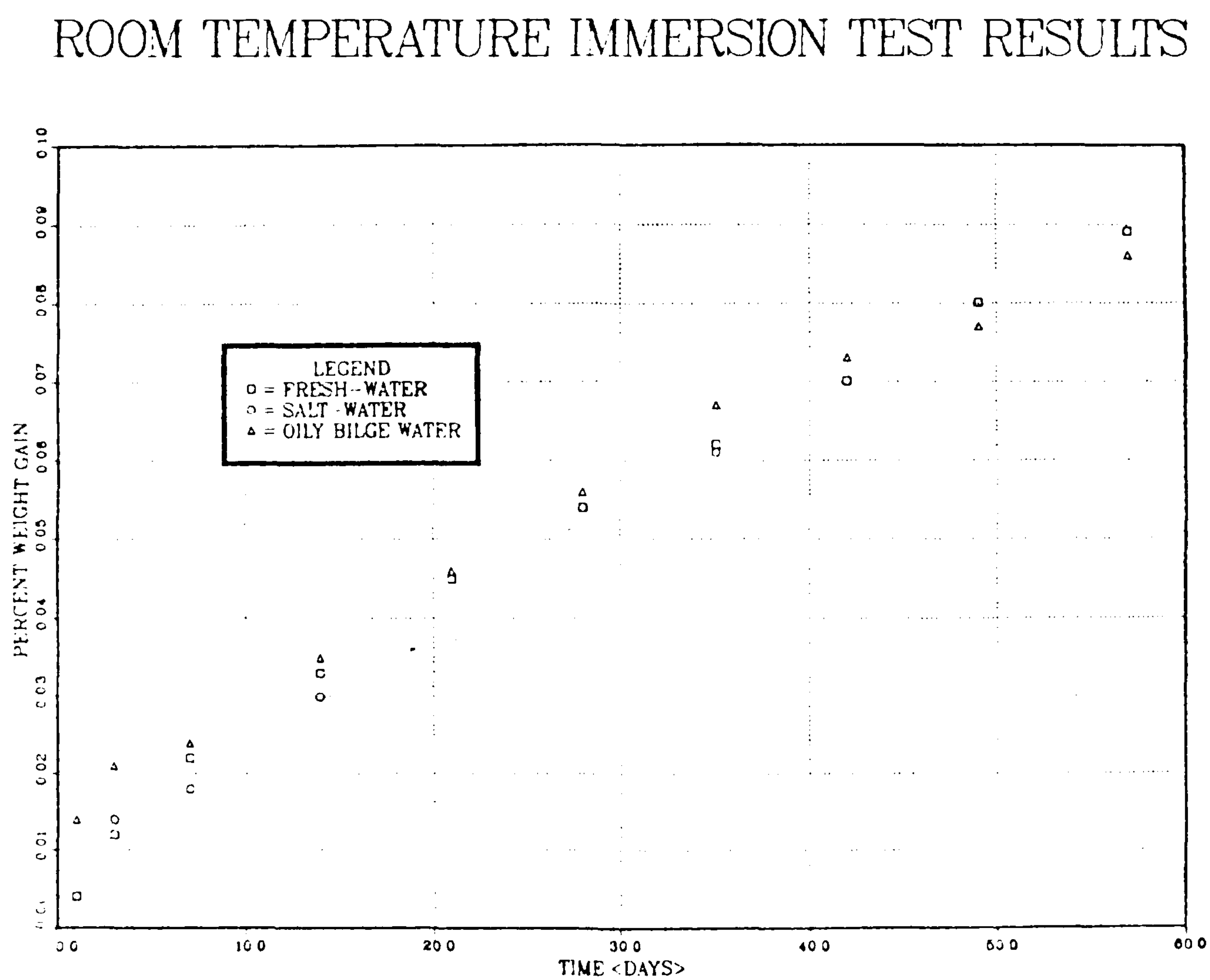

Figure 20. Room Temperature Immersion Test Results

Resins Corporation and for the chock samples used in this experiment. This ratio was two times greater for the ASTM samples. The chocks used in this experiment outweighed the small ASTM samples by a factor of ten.

According to the steady state diffusion equation, the flux is equal to the product of the cross sectional area of the surface normal to the flow, a coefficient, and the driving force which is the concentration gradient [Ref. 13]. Assuming this gradient to be steady with time (which it may not be), it seems to be reasonable that the smaller, lighter sample with a greater surface area to volume ratio should absorb more moisture in a given period of time. With this in mind, the fact that the earlier tests showed from 2 to 5 times greater percentage of fresh-water absorption than this experiment is not surprising. No long term absorption rate data was available for salt-water and no comparisons could be made.

Figures 21, 22, and 23 are plots of immersion tests in each fluid which compare the weight gain of the full surface area exposures to chocks that were held between two gasketed plates with only their edges exposed to the fluid. The ratio of full surface area to partial surface area exposures was approximately 2 to 1, but the difference in percent weight gain was not nearly as dramatic, as can be seen in the above referenced figures. It is possible that some water leaked between the gasket material and the sample surface, and was

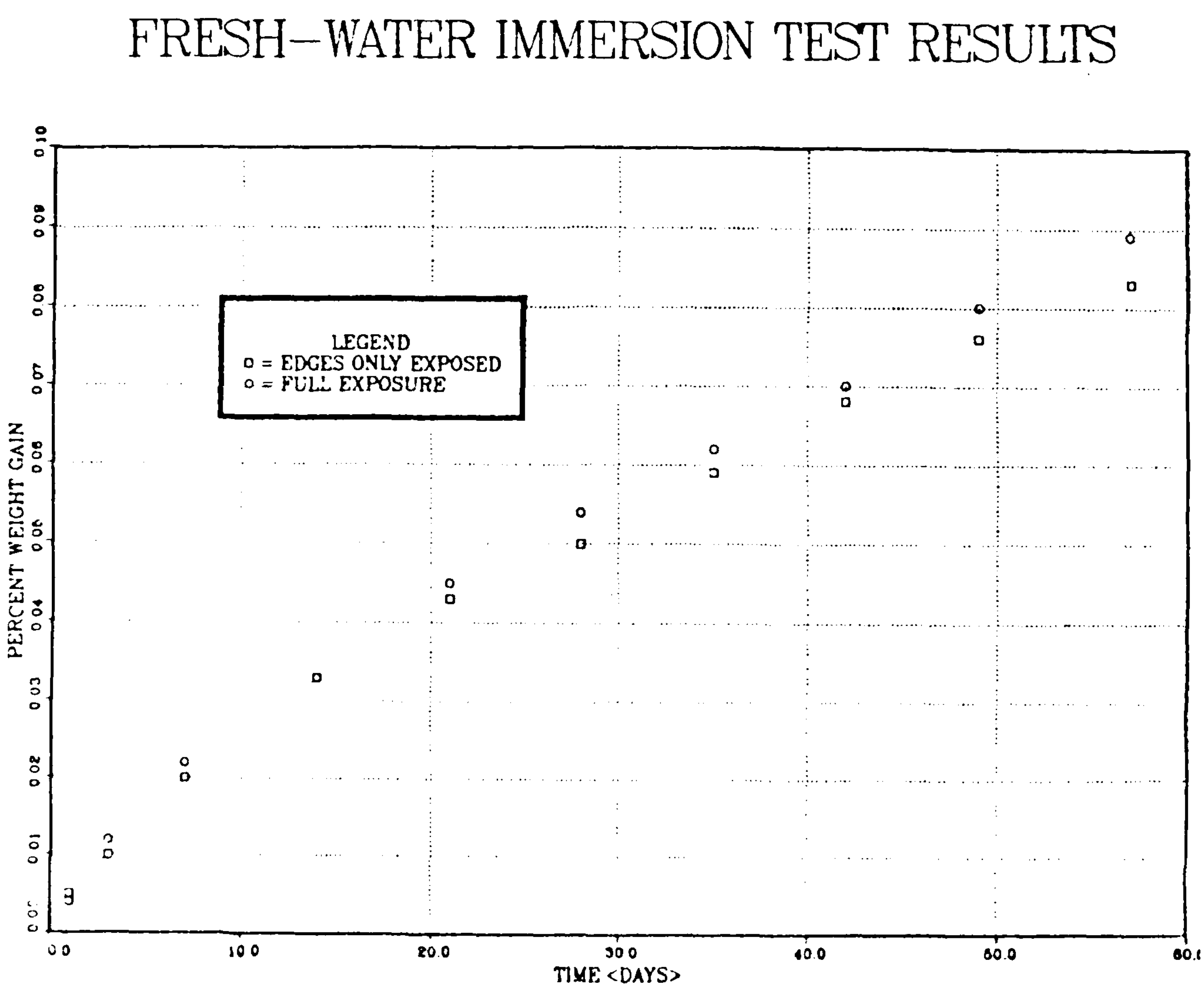

Figure 21. Fresh-Water Immersion Test Results

SALT-WATER IMMERSION TEST RESULTS

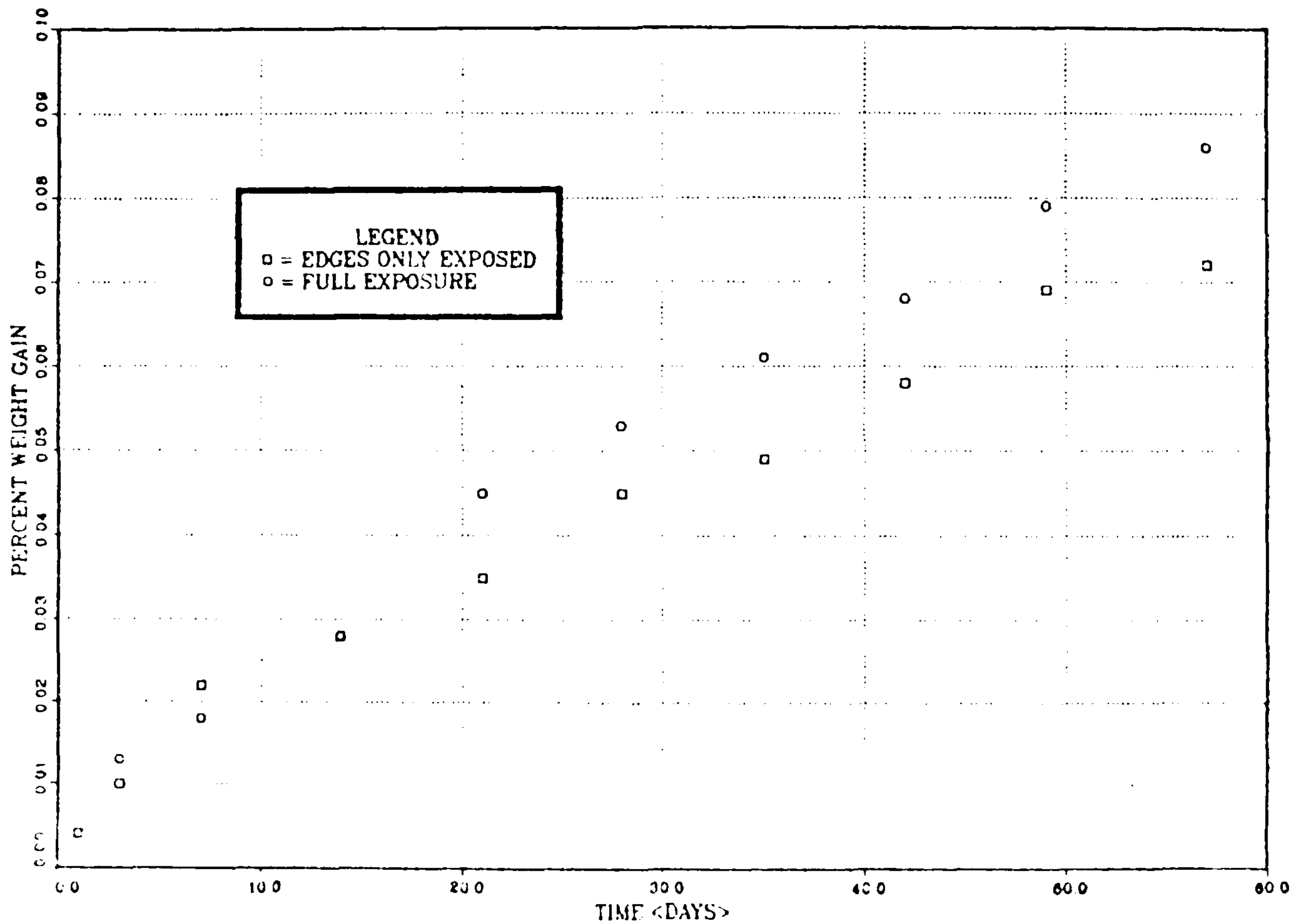

Figure 22. Salt-Water Immersion Test Results

OILY BILGE WATER IMMERSION TEST RESULTS

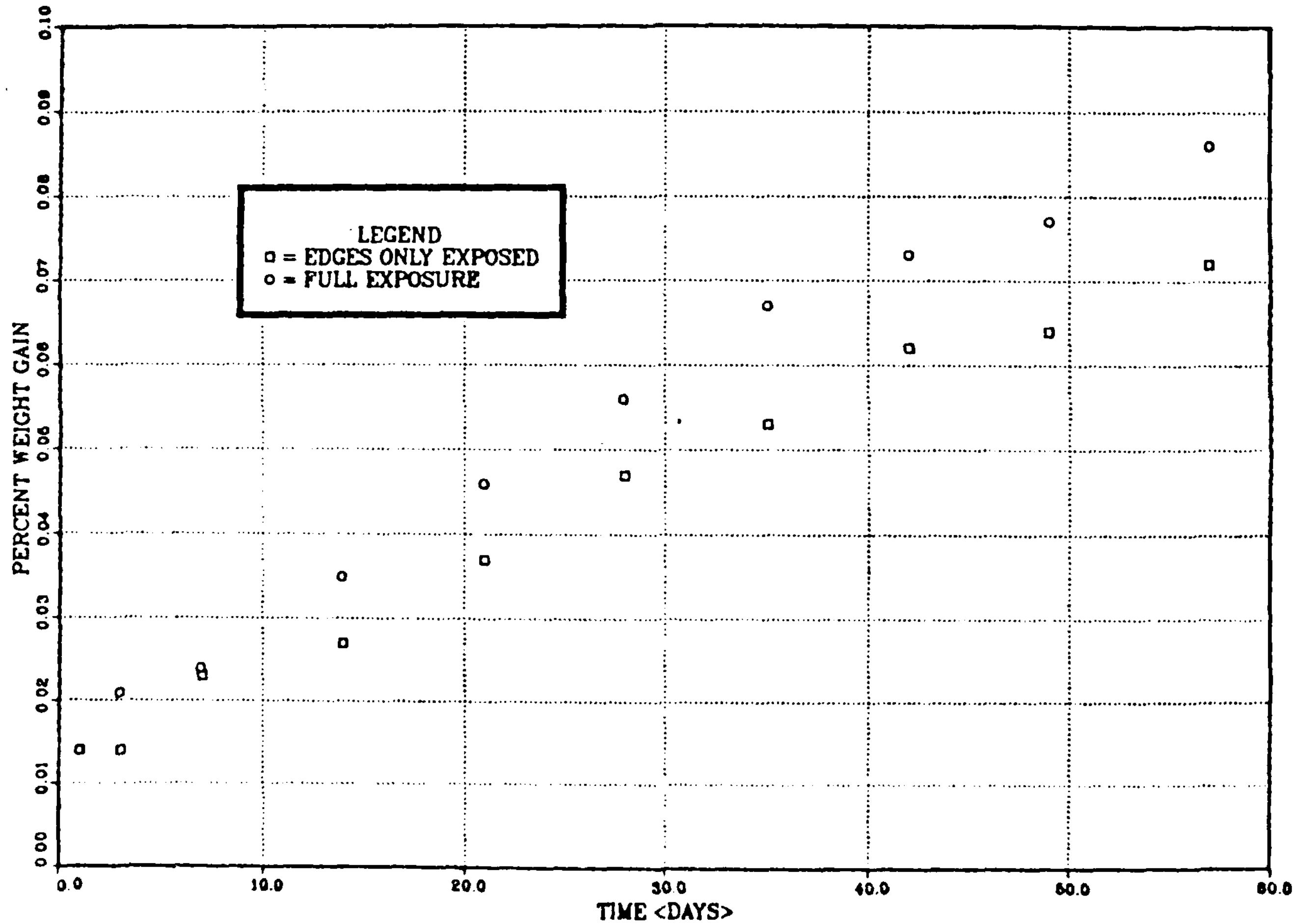

Figure 23. Oily Bilge Water Immersion Test Results

absorbed through the top and bottom surfaces. When the samples were removed from the gasketed test apparatus they appeared dry on the top and bottom surfaces. The oil samples, however, had the tightest seal as they were hard to unseat from the gaskets so that very little oil could have leaked to the concealed surfaces. No difference between quality of seal between the fresh-water and salt-water samples was observed, yet there was a greater difference between full and partial surface area exposures in the case of salt water. If leakage did occur in this test it is possible that it would occur in service as well, so it does not appear that full surface area exposure yielded overly severe results than may be expected in service.

Table 2 lists the ultimate compressive strengths of the chocks after immersion testing and it is apparent that

TABLE 2

Compressive Strength After Room Temperature Exposures

Exposure	Ult. Compressive Strength (psi)
Control	19400
Fresh-water (4 wks)	18700
Fresh-water (8 wks)	19500
Salt-water (4 wks)	19000
Salt-water (8 wks)	19000
Bilge water (4 wks)	19100
Bilge water (8 wks)	19100

the strength was unaffected by these exposures. Figure 24 compares the stress-strain data for the material after 8 weeks immersion in the three different fluids, with no detrimental effects observed.

B. EXPOSURE DURING CURING PROCESS TEST

The results of this test are listed in Table 3. The reader may recall that the chocks for this experiment were cured in a small aluminum mould which resembled an actual installation type setup, and it was considered likely that the chocks cured at a lower internal temperature than in the case of the silicon mould samples. The ultimate compressive strength of the chocks from the small mould was 18800 PSI, about 500 PSI below the average control strength for chocks cured in the silicon moulds. Bubbles were noted on the surface of the chock despite the angle of inclination and the opening provided for overfill. The presence of bubbles would most likely occur in an actual service installation, and it did not appear to effect the strength of the material.

The material that was cured at 15 degrees C (59 degrees F) and 95-100% RH had an ultimate compressive strength 18 percent below that of the material cured at room temperature and ambient relative humidity. This is a significant reduction in strength and is a source for further investigation. The manufacturer's instructions allow the chocks to be cured at a plate temperature of 16 degrees C for 48 hours, and this test indicates a significant loss in strength at the

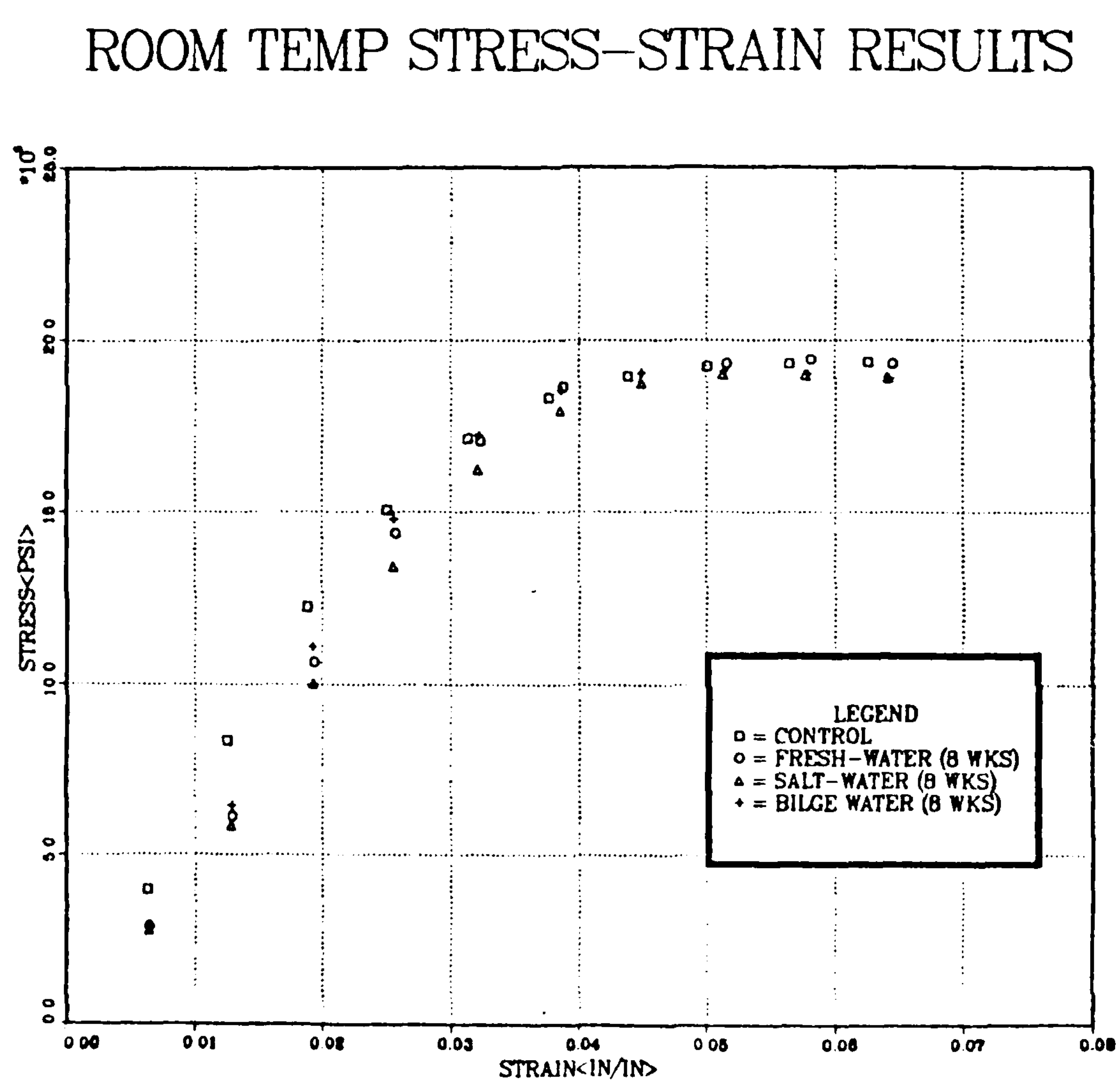

Figure 24. Room Temperature Stress-Strain Results

TABLE 3

Compressive Strength After Curing Exposures

Exposure (48 hrs)	Ult. Compressive Strength (psi)
Control (22C--40% RH)	18800
25C--95-100% RH	18300
40C--95-100% RH	18900
*15C--95-100% RH	15400

* Cured an additional 48 hrs. at 22C--40% RH

lower allowed temperature and nearly 100 percent RH. The exotherm temperature was not determined for this experiment and these chocks were made with the full reduction of hardener employed. Because there was only a slight decrease in strength in the room temperature cured chocks and a large decrease in strength in the 15 degree C cured chocks, further research into this topic would be beneficial.

C. ACCELERATED TESTS

Figure 25 compares the various weight gains for three different exposure tests. It is apparent that the 80 degree C water immersion test yielded the most rapid absorption rate. Figure 26 compares the ultimate compressive strengths of the chocks for various exposure tests. An elevated level of strength for the 80 degree C water immersion and humidity chamber tests was observed and previous testing indicated that the strength does increase with elevated temperature

ELEVATED TEMPERATURE TESTS RESULTS

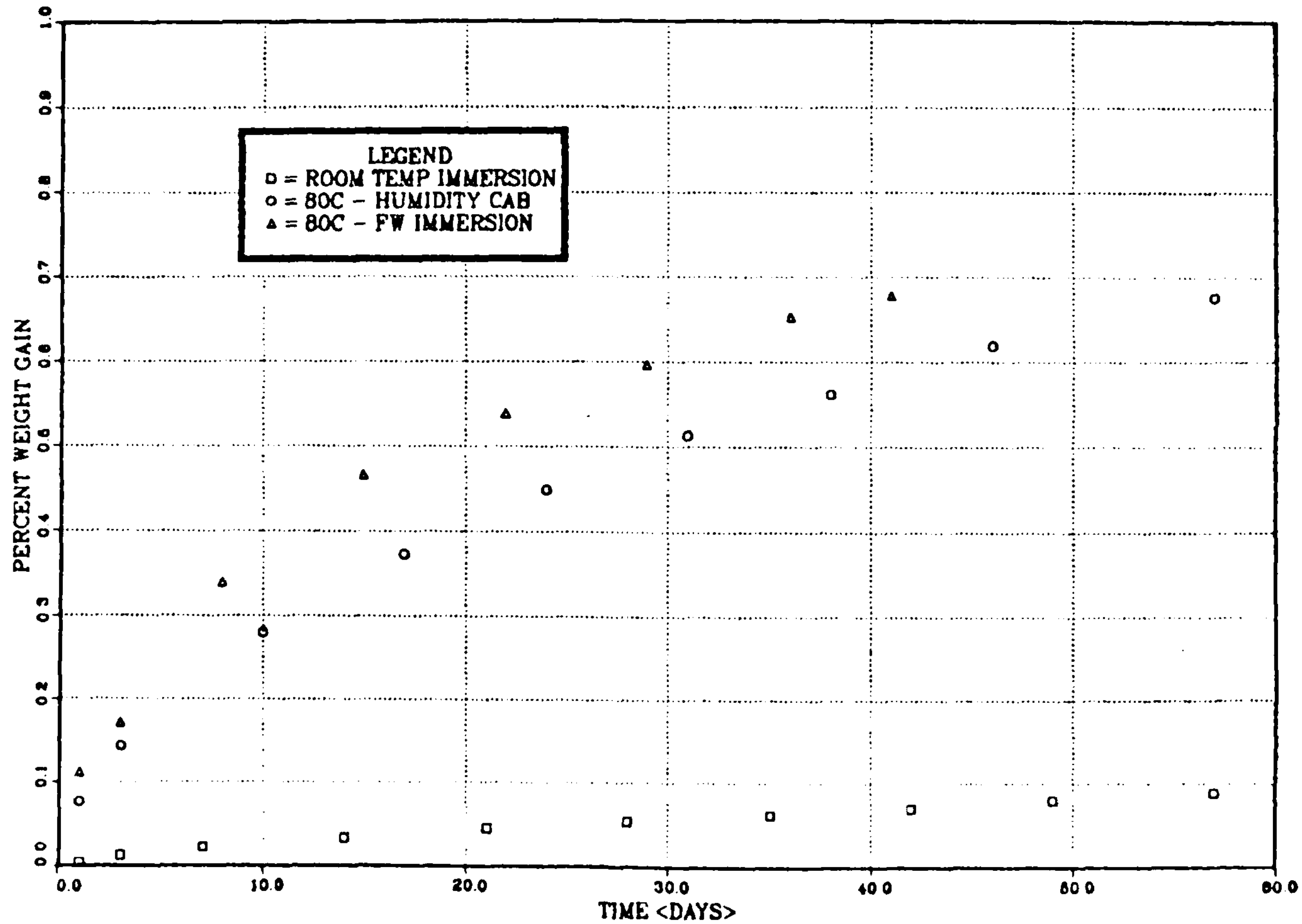

Figure 25. Elevated Temperature Test Results

ACCELERATED TEST STRENGTH RESULTS

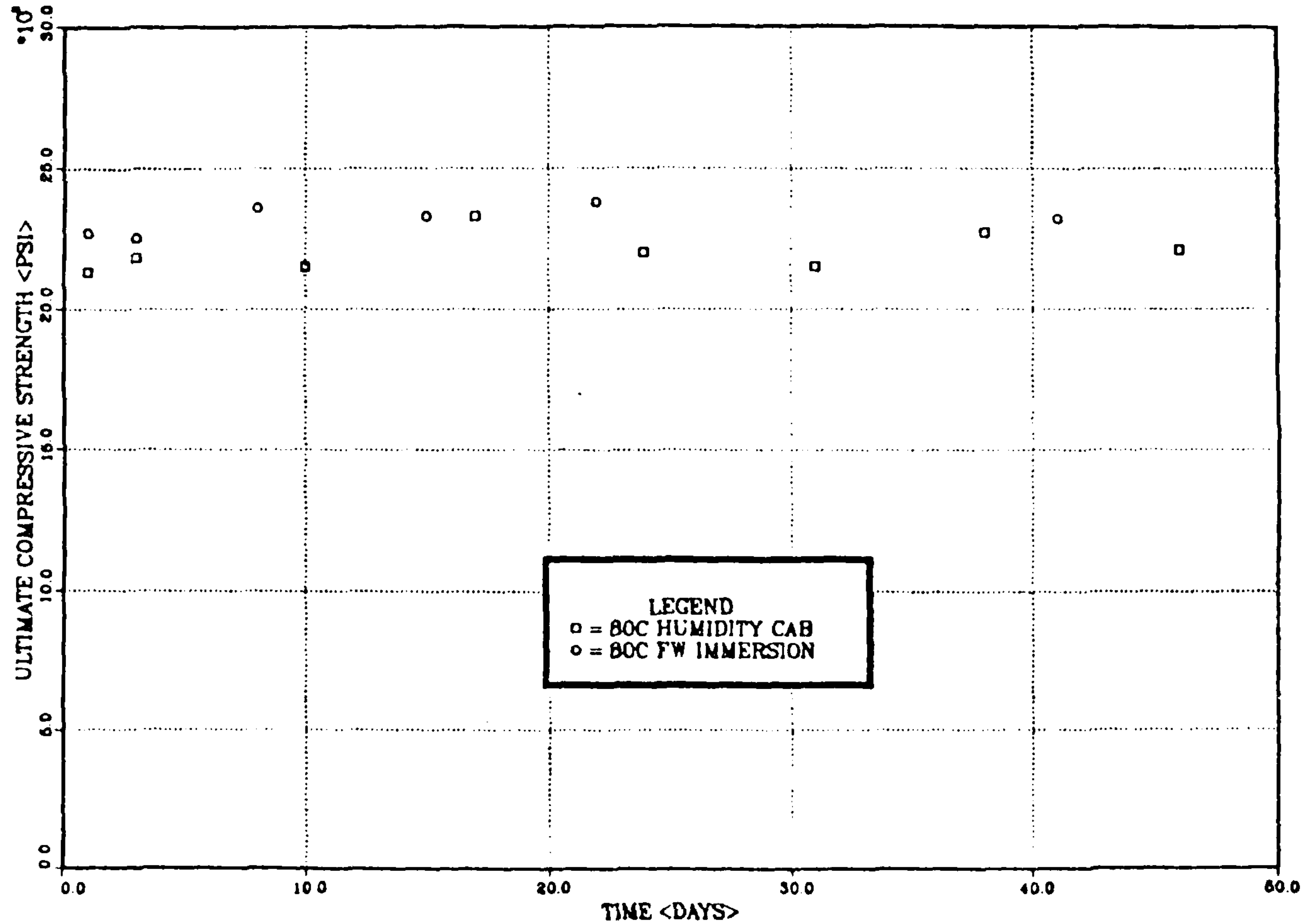

Figure 26. Accelerated Test Strength Results

post cure. A maximum of approximately 0.67 percent moisture absorption was achieved after 8 weeks of exposure to 80 degrees C and 95-100 percent RH, and 5 weeks of immersion in 80 degree C water. There was no loss in strength observed in either case.

No destructive effects were observed in either of the accelerated temperature tests for this material. The 80 degree C water immersion test produced an absorption rate almost twice that of the humidity chamber exposure, and an order of magnitude (i.e. tenfold), greater than room temperature immersion. It is apparent from these results that this type of material must be exposed in an accelerated test to obtain significant absorption levels for long term design analysis.

Of interest is the fact that the 80 degree C humidity chamber test caused such a dramatic increase in moisture absorption. If the rate achieved in the experiment continued, the material would reach a level of 4.8 percent weight gain in a year, much higher than the 1.2 percent observed by previous tests with room temperature immersion. It should be noted that, while asymptotic behavior was only observed in the room temperature bilge oil chocks and the 80C fresh-water immersed chocks, it would be an expected result in all cases if the tests were allowed to run for a longer period of time. The technique definitely caused great acceleration in the aging process with no degradation in appearance or strength and proved to be an effective aging method. Since the 80 degree

C test temperature was chosen because it was the maximum temperature that the chocks can be exposed to in service, the test was not that severe considering high humidity levels are likely to be encountered in service. While no losses in strength were observed for this technique, the test could not run long enough to achieve a moisture level comparable to what might exist after 5 to 10 years of service. It appeared to be a reasonable test to employ to make these determinations in the future.

The 80 degree C water immersion test yielded moisture levels about 20 percent higher than the humidity chamber exposure. Figures 27 and 28 compare stress-strain data after 3 and 6 weeks of exposure to the two respective acceleration test environments. No significant departures from control stress-strain curves were observed, except for the continued rise in the compressive strength after a strain of 0.06 in/in, which was most likely due to the elevated temperature effect. The curve beyond this strain is of little practical interest, however, because corresponding deformations approach 0.10 in for 1.25 in chocks, which would probably result in misalignment of the supported machinery. From the plots it does not appear that the 80 degree C immersion has an oversevere effect on either the ultimate compressive strength or the stress-strain curve. Since the aging process is a time dependent one and these chocks were exposed to both elevated temperatures and 95-100 percent RH, it is difficult to explain why the humidity chamber and 80 degree C immersion data seemed

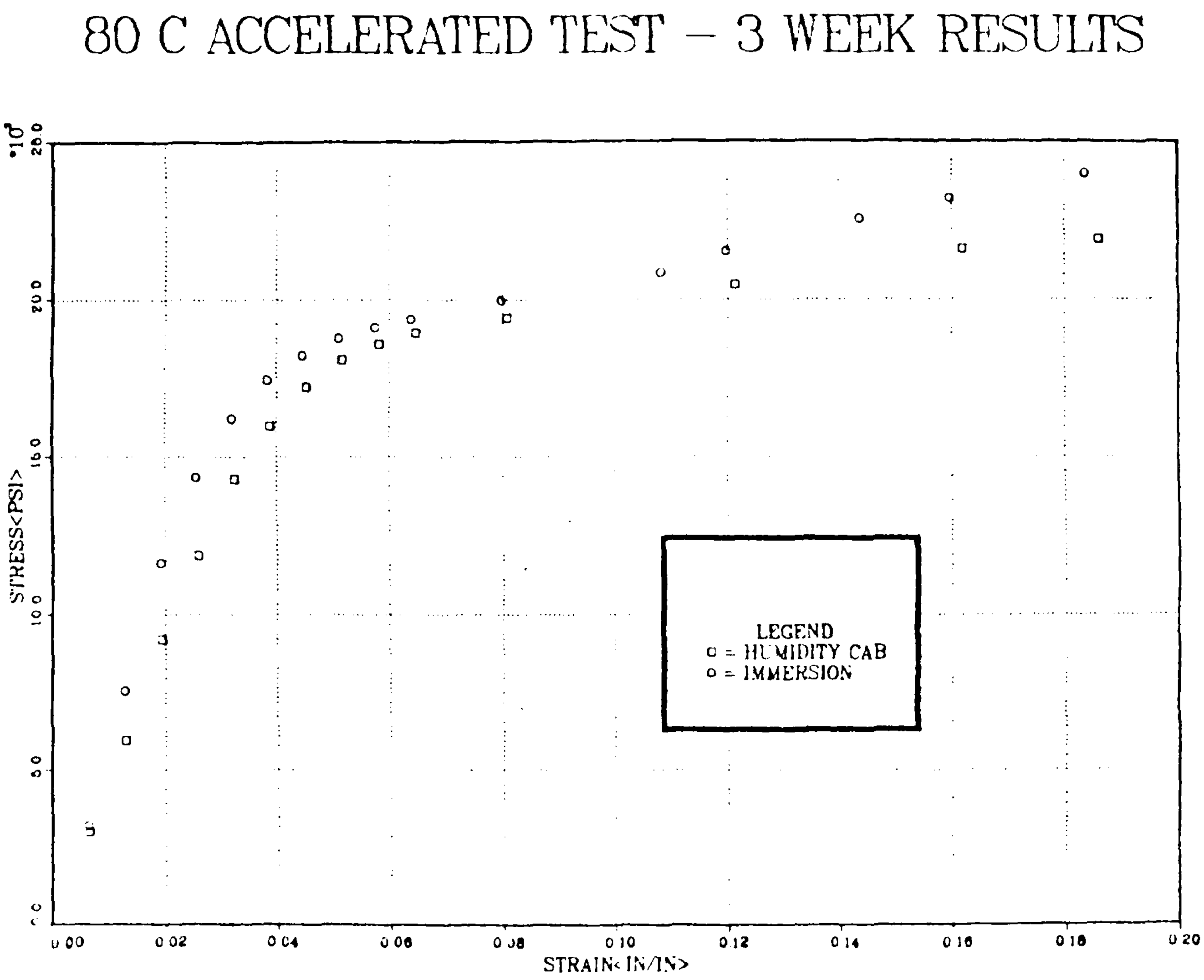

Figure 27. 80C Accelerated Test Results for 3 Weeks Exposure

80 C ACCELERATED TEST – 6 WEEK RESULTS

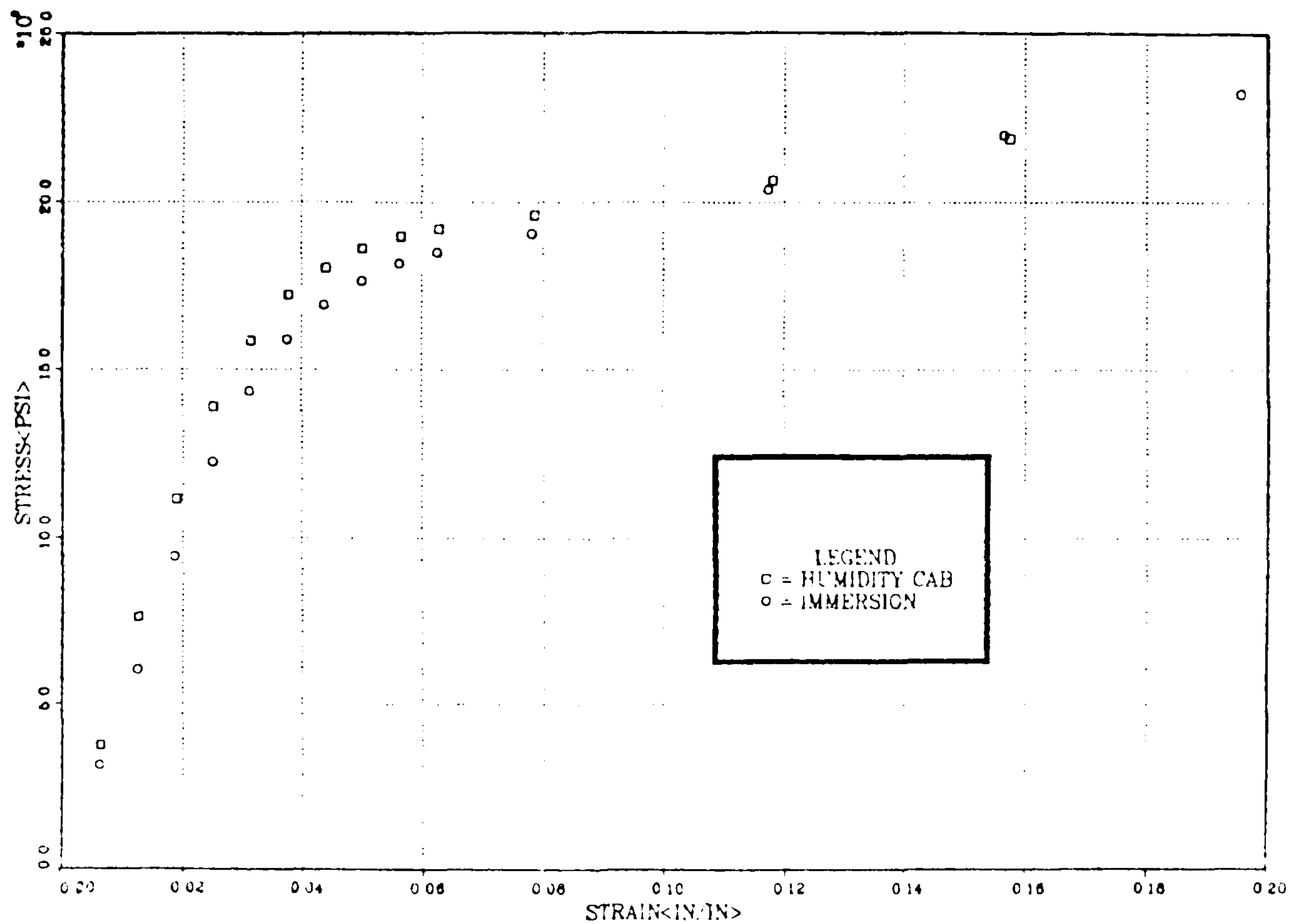

Figure 28. 80C Accelerated Test Results for 6 Weeks Exposure

to exhibit conflicting trends betw-en the 3 and 6 week periods. It is possible that the scatter in a sample size of 3 was too large to place much confidence in this shift; however, the error analysis performed indicated the stresses are good to plus or minus 100 psi.

D. EDGE ABSORPTION RATE TEST

The absorption rate for the chocks with only the cured surface exposed was lower by 25 percent than the samples with the saw cut edges exposed. These test results have severe limitations. First, there was large scatter in the data, which casts doubt on the reliability of the average values obtained. Second, it appeared that the RTV silicon sealer absorbed water as well as the chocks, which resulted in much higher overall weight gains. An examination of the surfaces after removal of the sealer indicated that they were relatively dry when compared to unsealed surfaces. This test was hastily prepared toward the end of experimentation and the merit of this result is questionable.

E. FAILURE DURING COMPRESSION TESTS

In approximately 30 percent of the chocks tested an audible snapping noise was heard after they had deformed between 0.02 and 0.04 inches. This noise was thought to be the development of a crack in the chock but had no apparent effect on the ultimate compressive strength of the material when compared to chocks with the same exposure that did not experience this trait. This characteristic was not

encountered in any chocks that were exposed to elevated temperatures and moisture.

Chocks that were exposed to elevated temperatures to accelerate moisture absorption demonstrated higher ultimate compressive strengths than the room temperature samples. The strengths were about the same until the chocks were compressed by about 0.075 in, at which time room temperature exposed samples generally failed slowly, while the elevated temperature/humidity samples continued increasing in strength until 0.25-0.30 in deformation. When this point was reached, the samples failed catastrophically. Figure 29 shows the failure mode for samples exposed to elevated temperature and moisture. The upper chock was immersed in 80 degrees C fresh-water and the lower was aged in the humidity chamber for two weeks at the same temperature and 95-100% RH. Another trait that was observed in almost all chocks to some degree was the star-like marks on the sides of the samples after compression testing, as shown in Figure 30. In general, any mechanical system that undergoes compressive loading is subject to a catastrophic loss of strength due to buckling [Ref. 14]. The star-like marks are possible signs of local instabilities which indicate the ultimate mode of failure may have been buckling.

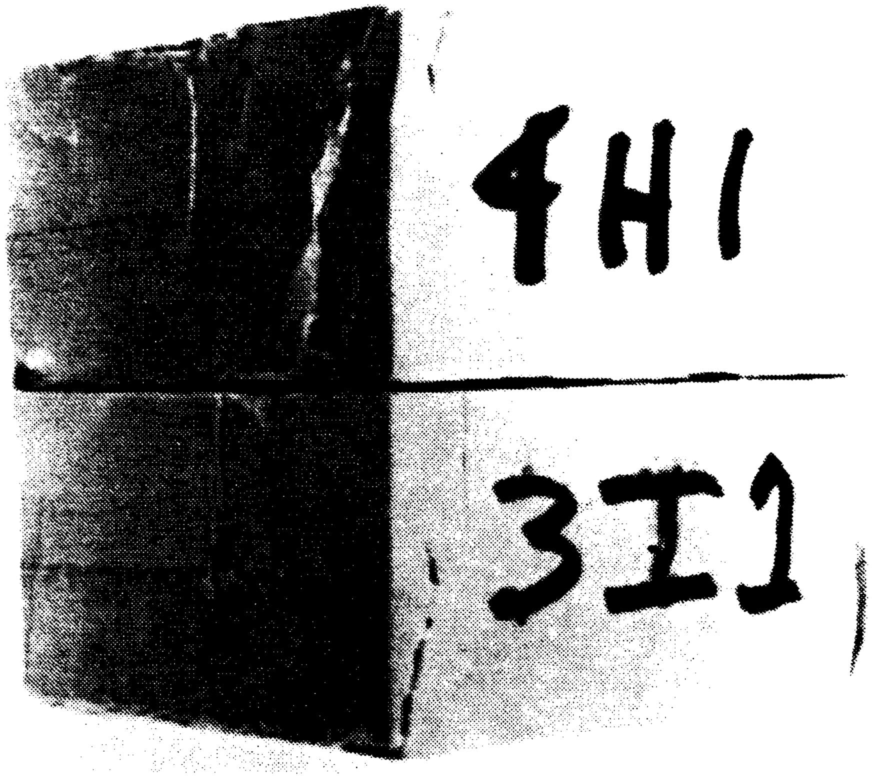

Figure 29. Chocks After Compression Test

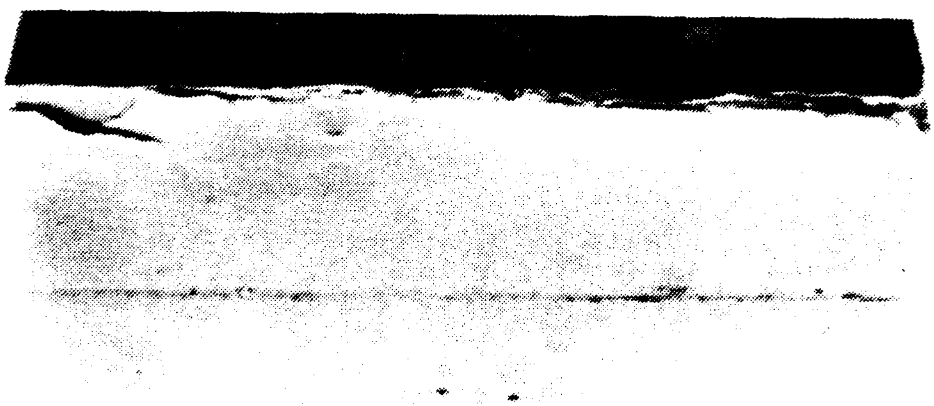

Figure 30. Star-Like Marks After Failure

VI. CONCLUSIONS AND RECOMMENDATIONS

Fresh-water, salt-water, and oily bilge water immersion did not cause a loss in ultimate compressive strength of the chocks tested over an eight week period. The stress-strain characteristics were also unaffected by this test method.

The weight gain percentage for samples exposed to fresh-water and salt-water appeared to be linear with respect to time after an initial rapid absorption rate during the first week. The oily bilge water immersed chocks started to slow their absorption rate at about 35 days. The fact that chocks in service will not have their full surface area exposed does not appear to dramatically lower the absorption rate.

The combination of low temperature (15 degrees C) and high relative humidity (95 to 100 percent) present during the curing process significantly reduced the ultimate compressive strength of the chocks tested in this experiment. Further research in this area would be useful because the manufacturer's procedures allow this material to be used at a low temperature of 16 degrees C (61 F) and do not address humidity whatsoever. A study should be performed in the 15 to 20 degree C range with varying levels of relative humidity to determine acceptable curing conditions for the chocks.

A slight reduction in ultimate compressive strength was observed in the smaller aluminum moulded chocks which may

have been caused by a lower curing temperature, the reduction of hardener, or a combination of both. Additional study of strength versus curing temperature would also be beneficial.

Both methods used to accelerate the effects of moisture on the material proved satisfactory. Absorption rates were increased by an order of magnitude with no oversevere effects observed in the stress-strain data. Immersion in fresh-water at 80 degrees C caused the most rapid weight gain in the chocks, but the immersion and humidity chamber curves appeared to be very similar in shape.

No loss in ultimate compressive strength was observed for this material up to 0.67 percent weight gain of water. Higher percentages could be achieved by a longer test period or possibly increasing the pressure as well as the temperature, but was not investigated in this thesis.

There is some indication that moisture absorption is dependent upon the surface area to volume ratio of the chocks; therefore, actual chocks in service should absorb less moisture than ASTM test results indicate for room temperature exposure. However, chocks in elevated temperature locations may absorb up to four times the moisture as a chock at room temperature. Expected service temperature and the geometry of the chock are important design considerations.

APPENDIX A

EQUIPMENT SPECIFICATIONS

Blue M Humidity Chamber Model FR 251B Ser. Number AA-677
220V, 7KW Range: -15C to 93C

Tineus-Olsen Super "L" Hydraulic Universal Testing Machine
200,000 lb capacity 240V, 60 cycle, 3 phase

Mettler Instrument Corporation Precision Balance Type H15
Ser. Number 126018 Capacity 160 grams Brown & Sharpe
Dial Indicator 0.001 in graduations Range: 1 in Ser.
Number 8241-942

APPENDIX B

ERROR ANALYSIS

Percent Weight Gain

Balance vernier scale readability	.0001 gm
range	.0003 gm
delay in taking reading	.0050 gm
δw, uncertainty in one reading	.0054 gm

The most extreme case occurs with the lightest shock and the greatest percent gain in weight.

Sample calculation for 3 chocks:

w_i, initial weight = 130.6439 gm

w_f, final weight = 129.7600 gm

δw = .0054 gm

P_1 = % wt gain in sample #1 = .6812

P_2 = % wt gain in sample #2 = .6698

P_3 = % wt gain in Sample #3 = .6772

$$P_{AV} = \frac{P_1 + P_2 + P_3}{3} = .6761$$

$$\frac{\delta P}{P} = \left[\left(\frac{\delta w_f \cdot 100}{w_f}\right)^2 + \left(\frac{\delta w_i \cdot 100}{w_i}\right)^2\right]^{1/2} = .0059$$

δP = .004%

The probable uncertainty of P_{AV} (mean of 3 chocks at a single data point):

$$\delta P_{AV} = \frac{\delta P}{\sqrt{n}} = .0023 \qquad \text{Then } P_1 = 0.681 \pm .003\%$$

Ultimate Compressive Strength

δP, Load Scale Readability = 300 #

δL_1, δL_2, uncertainty in dimensions = .005 in

P_{max}, maximum load for 1 chock = 91500 #

σ_1, ult. compressive strength in chock #1 = 23117 PSI

σ_2, ult. compressive strength in chock #2 = 22555 PSI

σ_3, ult. compressive strength in chock #3 = 22508 PSI

Stress-strain data is reported from 0 to 23000 PSI so sample error analysis was done for σ_{low}, σ_{middle}, and σ_{ult}:

$$\sigma_{ult} = \frac{\delta\sigma_{ult}}{\sigma_{ult}} = [(\frac{300}{91500})^2]^{1/2} = .0033 \rightarrow \delta\sigma_{ult} = 76.3 \text{ PSI}$$

$$\sigma_{mid} = \frac{\delta\sigma_{mid}}{\sigma_{mid}} = [(\frac{300}{60000})]^{1/2} = .005 \rightarrow \delta\sigma_{mid} = 75 \text{ PSI}$$

$$\sigma_{low} = \frac{\delta\sigma_{low}}{\sigma_{low}} = [(\frac{300}{32500})^2]^{1/2} = .009 \rightarrow \delta\sigma_{low} = 75 \text{ PSI}$$

Note: uncertainty in load bearing dimensions is very small compared to load and was neglected.

For three samples at one data point:

$$\delta\sigma_{AV} = \frac{\delta\sigma}{\sqrt{n}} = 44 \text{ PSI}$$

Then $\sigma = 22700 \pm 100$ PSI

Strain

δe_1; uncertainty in dial indicator .001 in

δL_1, uncertainty in chocks initial thickness .001 in

e_1, compressive deformation .032 in

L_1, initial thickness of 1 chock 1.244 in

$e_2 = .032$ in

$e_3 = .032$ in

$e_{kv} = .032$ in

$$\varepsilon_1 = \frac{e_1}{L_1} = .0257 \frac{in}{in}$$

$$\frac{\delta\varepsilon}{\varepsilon} = [(\frac{\delta e_1}{e_1})^2 + (\frac{\delta L_1}{L_1})^2]^{1/2} = .0313 \rightarrow \delta\varepsilon = .001$$

For three samples at one data point:

$$\delta\varepsilon_{AV} = \frac{\delta\varepsilon_1}{\sqrt{n}} = .0005$$

Then $\varepsilon_{AV} = .026 \pm .001 \frac{in}{in}$

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